ARL-TM-2015 ● DEC 2015

US Army Research Laboratory

Volume I: Select Presentations

by ARL Summer Student Research Symposium

NOTICES

Disclaimers

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1. REPORT DATE *(DD-MM-YYYY)* December 2015	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)**
4. TITLE AND SUBTITLE Volume I: Select Presentations		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) ARL Summer Student Research Symposium		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1138		**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TM-2015
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The ARL Summer Student Research Symposium is an ARL Director’s Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.

All college undergraduate and graduate students receiving research appointments and conducting summer studies at ARL are automatically enrolled in the symposium program. As an integral part of their summer study, all students are required to write a paper on their work which summarizes their major activity and its end product.

The program is conducted on two separate competitive levels: undergraduate and graduate. The format of the paper in both levels is the same. However, the evaluation will take into consideration the difference in the academic level of the students.

All students submitted their research paper for directorate review. Directorate judging panels selected one or two papers from each competition category for the laboratory-wide competition at the Summer Student Symposium on 7 August 2015.

Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 7 August 2015. At the symposium the students gave presentations on the focuses of their research papers to the ARL Director and an ARL Fellows panel.

This volume of the Summer Student Symposium Proceedings contains many of the presentations that the selected students gave at the symposium.

15. SUBJECT TERMS

ARL Summer Student Research, SEAP

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr Vallen Emery
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU	116	**19b. TELEPHONE NUMBER (Include area code)** (301) 394-3585

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Contents

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Director’s Foreword

The U.S. Army Research Laboratory (ARL) mission is to “Provide innovative science, technology, and analyses to enable full spectrum operations.” As the Army’s corporate laboratory, we provide the technological underpinnings critical to providing capabilities required by our current and future Soldiers.

Our nation is projected to experience a shortage of scientists and engineers. ARL recognizes the criticality of intellectual capital in generating capabilities for the Army. As the Army’s corporate laboratory, addressing the projected shortfall is a key responsibility for us. We have, therefore, identified the nation’s next generation of scientists and engineers as a key community of interest and have generated a robust educational outreach program to strengthen and support them. We have achieved many successes with this community. We believe that the breadth and depth of our outreach programs will have a significant positive effect on the participants, facilitating their journey toward becoming this Nation’s next generation of scientists and engineers.

A fundamental component of our outreach program is to provide students research experiences at ARL. During the summer of 2013, we supported research experiences at ARL for over 175 undergraduate and graduate students. Each of these students writes a paper describing the results of the work they performed while at ARL. All of the papers were of high quality, but only a few could be selected for presentation at our student symposium. Several of the presentations for the selected research papers prepared this summer are contained in this volume of the proceedings, and they indicate that there were many excellent research projects with outstanding results. It is unfortunate that there was not enough time for us to have all of the papers presented. We would have enjoyed hearing them all.

We are very pleased to have hosted this outstanding group of students for the summer. It is our hope that they will continue their pursuit of technical degrees and will someday assist us in providing critical technologies for our Soldiers.

Thomas P. Russell
Director

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Introduction

The ARL Summer Student Research Symposium is an ARL Director's Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.

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Computational and Information Sciences Directorate (CISD)

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Enhanced Experience Replay for Deep Reinforcement Learning

August 7, 2015

Bryan Dawson
Senior – University of Maryland Baltimore County
Computer Science

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Introduction

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- The Army of the future will require many autonomous systems.
- Impossible to build robust systems using hardcoded rules.
- Battlefield environment is dynamic and unpredictable.
- Need to develop adaptive algorithms to handle these challenges.

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Reinforcement Learning
ARL
• Unsupervised – learning through experience
• Agent develops policy through exploration
• Actions → Consequences
• General learning paradigm
Actions
Observations
http://usaircraftpics.blogspot.com/2012/03/rq-11-raven-us-army-unmanned-aerial.html
https://upload.wikimedia.org/wikipedia/commons/7/74/Stark_contrasts_in_Afghanistan_-_080907-F-0168M-071.jpg
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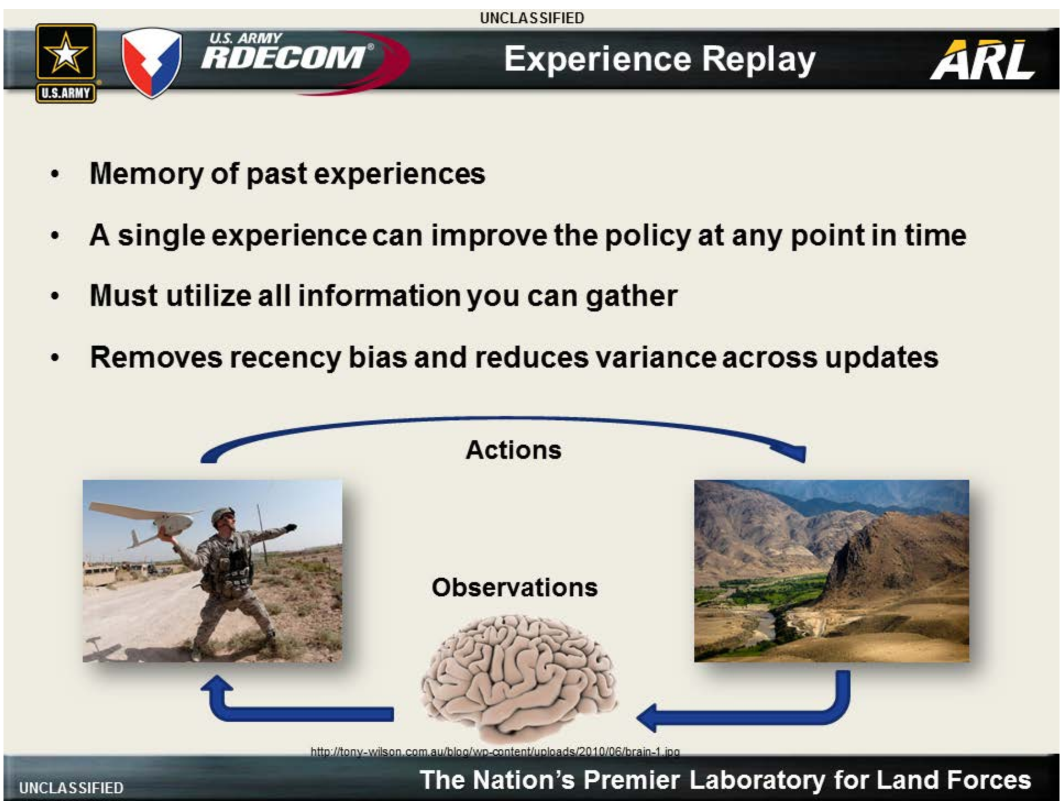
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Experience Replay
ARL
• Memory of past experiences
• A single experience can improve the policy at any point in time
• Must utilize all information you can gather
• Removes recency bias and reduces variance across updates
Actions
Observations
http://tony-wilson.com.au/blog/wp-content/uploads/2010/06/brain-1.jpg
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Army = Video Games ?

Army Battlefield Strategy	Video Game
1) Collect data from distributed sensors	1) Collect pixels from game output
2) Analyze data	2) Analyze data
3) Develop/decide on strategy	3) Develop/decide on strategy
4) Take action (troop movement, etc.)	4) Take action (move Mario, etc.)

http://www.mariogames.name/mario_image/super-mario-bros-deluxe.jpg

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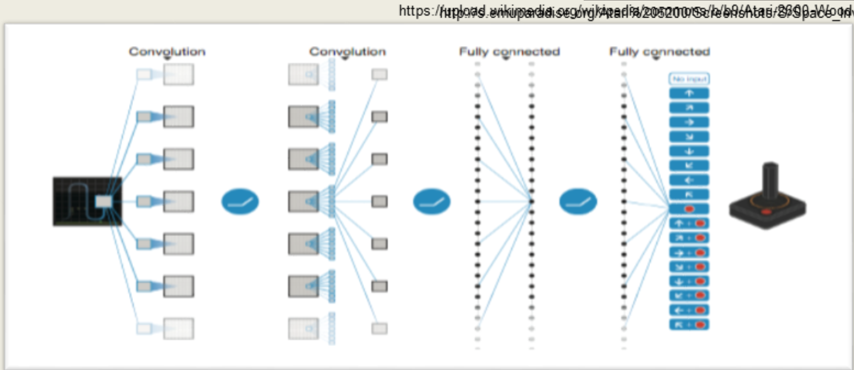
Atari Deep Learning

- Uses a convolutional neural network
- Raw frame → expected value of actions
- 10 days of training on 2496 cores!

https://upload.wikimedia.org/wikipedia/commons/b/b9/Atari-2600-Wood-4Sw-Set.jpg
http://s.emuparadise.org/Atari%202600/Screenshots/S/Space_Invaders_1.png



http://www.nature.com/nature/journal/v518/n7540/carousel/nature14236-f1.jpg

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System Performance

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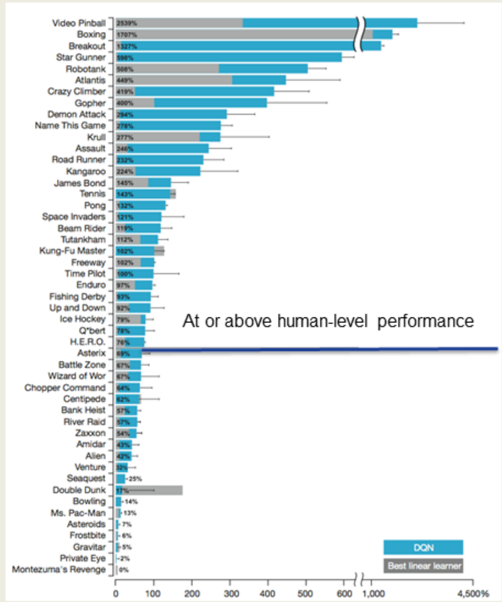

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System Performance

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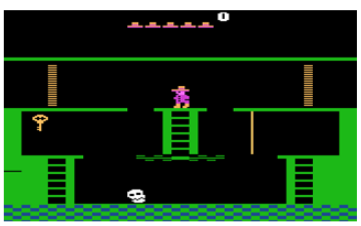
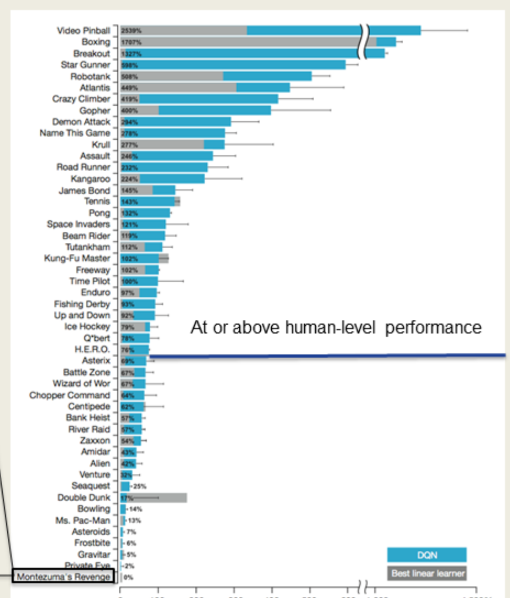
https://atariage.com/screenshot_page.php?SoftwareLabelID=310



Montezuma's Revenge

- Complex game
- Hard to obtain rewards
- Difficult to define action policy



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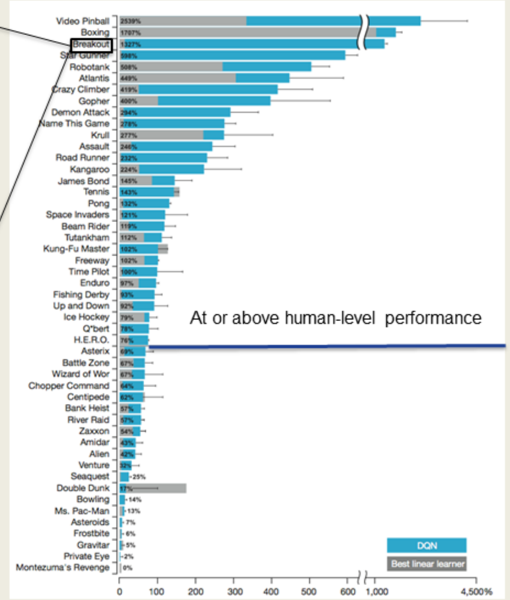
System Performance

https://en.wikipedia.org/wiki/Breakout_(video_game)

Breakout

- Simple game
- Easy to obtain rewards
- Easy to define action policy



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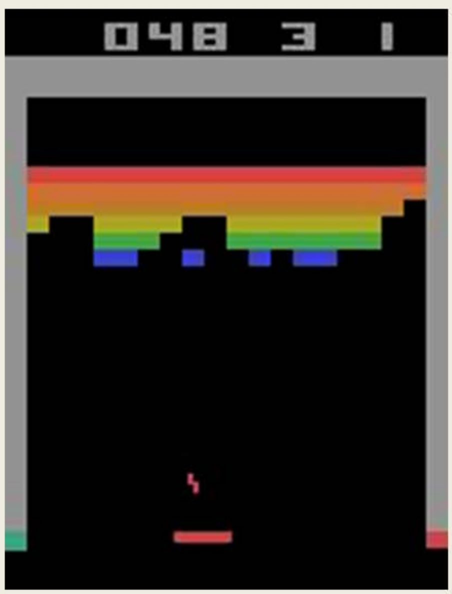
System Performance



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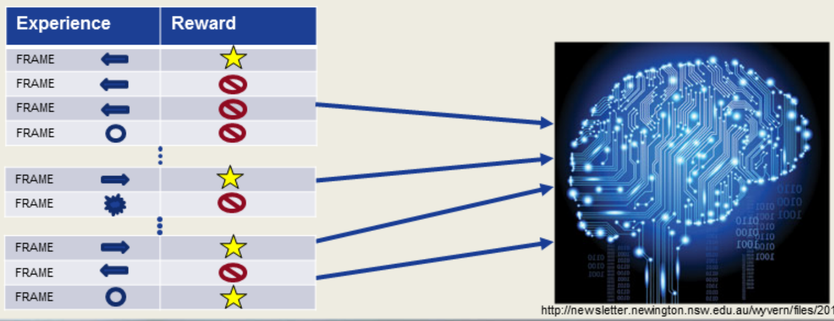
Reward-Biased Replay

Problem:

- Default sampling does not emphasize winning.
- Delayed reward signal – hard to correlate actions with rewards.

Solution:

- When the agent receives a reward, perform extra policy updates with recent experiences.



http://newsletter.newington.nsw.edu.au/wyvern/files/2014/05/Digital-Brain-1000x440.jpg

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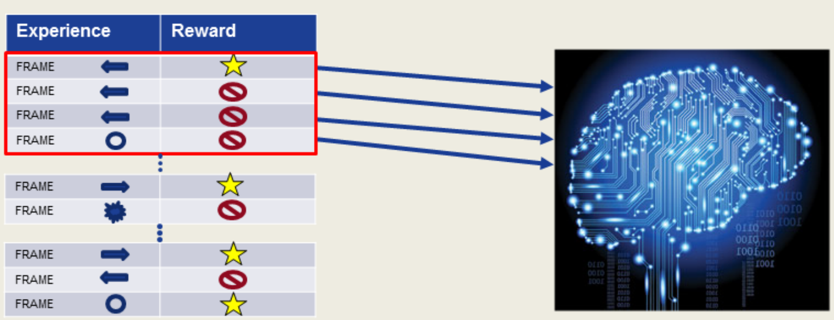

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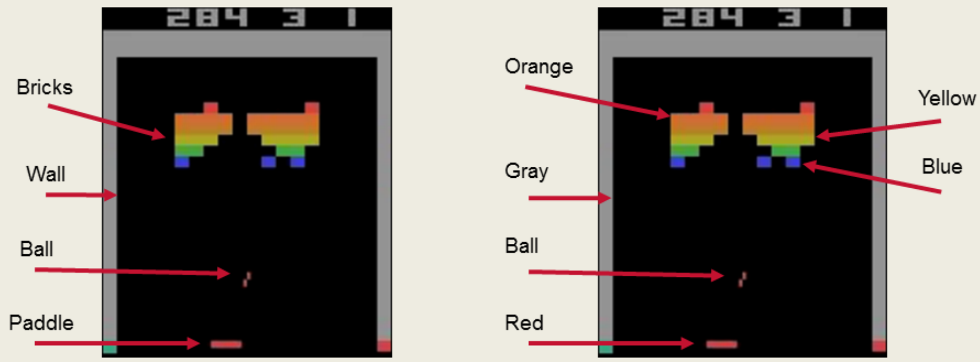
Representation Pre-training

Problem:

- Agent learns how to represent the game as it learns what to do with those representations.
- Evolving representations negatively affect learning.



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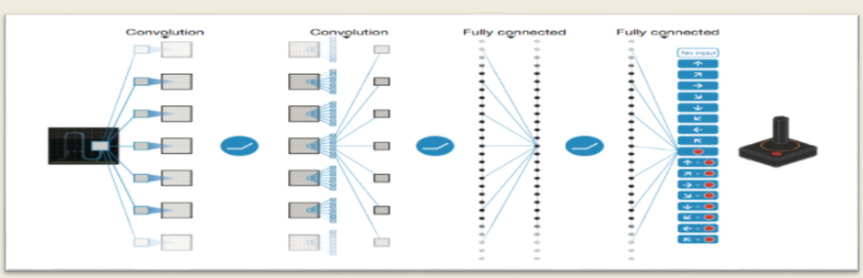
- Lock convolutional layers and retrain linear layers from scratch.



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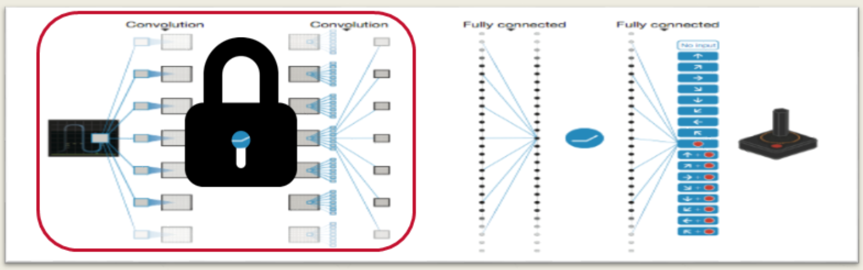

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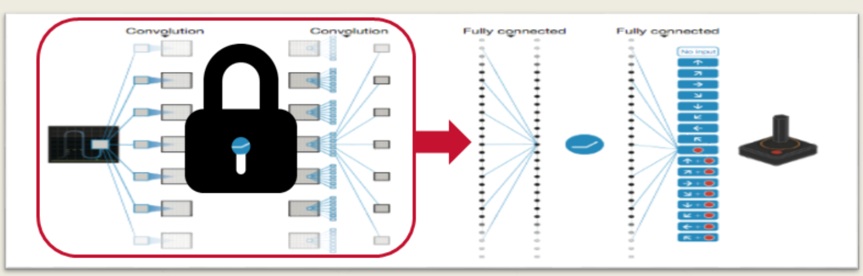

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Repetition Inhibition

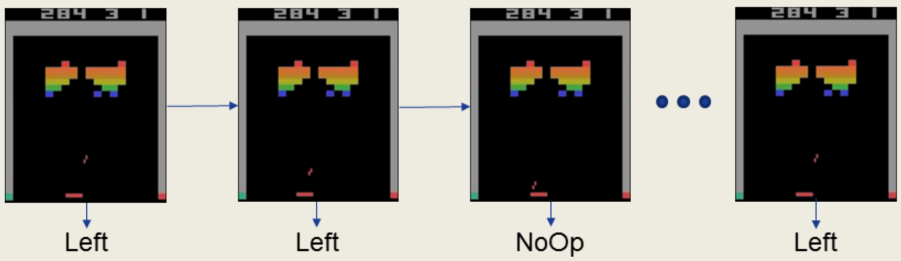
ARL

Problem:

- **Game keeps getting stuck in loops.**
- **Loops during training can oversaturate replay memory.**

Solution:

- **Examine most recent frames during training.**
- **If current frame has been seen recently, make random move instead of following policy.**
- **Break loops and force exploration.**



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Preliminary Results

Representation Pre-training

- Achieved reported performance in ONE day of training.
- 10x Speed-up!
- Can test algorithmic adjustments in significantly less time.

Repetition Inhibition

- ~50,000 loops were identified and avoided during training.
- Loops still encountered during preliminary testing.

Reward-Biased Replay

- Successfully sampled actions that triggered rewards.
- Evaluating our results to determine the effect on the system.

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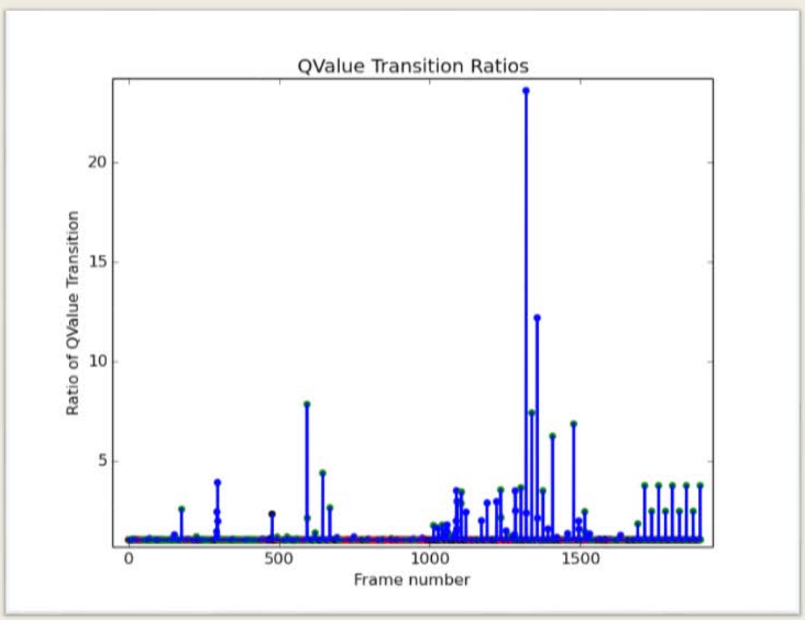
Future Work



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Future Work

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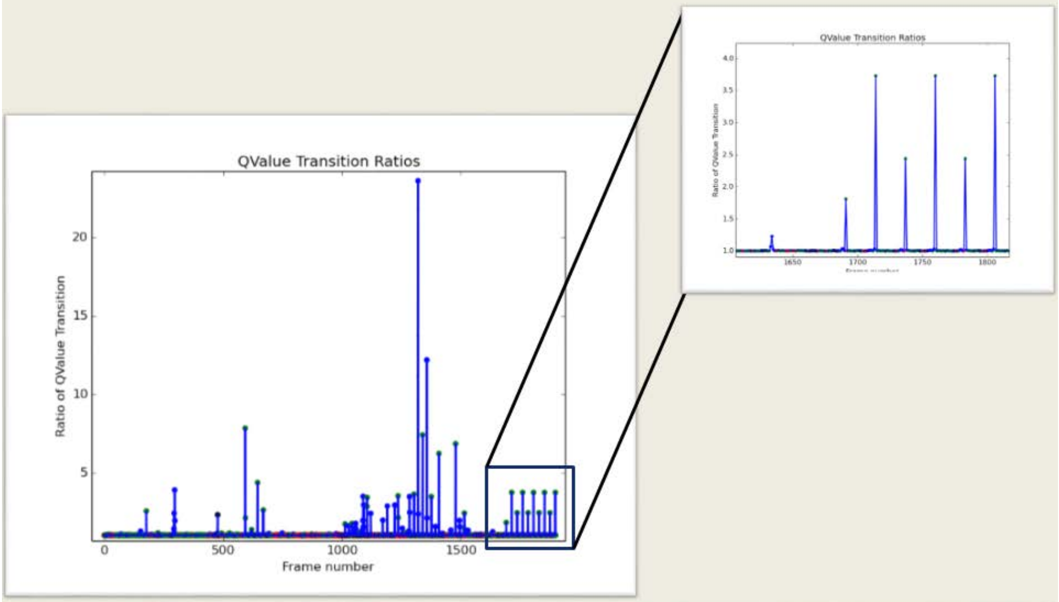

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Path Forward

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- Quantitative analysis of current results
- Investigate scalability of system using additional cores
- Implement additional modifications to system
- Explore collaboration and transition opportunities

http://www.arl.army.mil/www/pages/491/about_history_EnvisioningtheArmyIMG.png

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Acknowledgements

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A sincere thank you to

- Dr. David Doria
- Dr. Raju Namburu
- CISD
- Fellow interns

Questions?

TECHNOLOGY TO WIN

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Dislocation Density Evolution for FCC Materials Under Shock Loading

Presented by: Karoon Mackenchery[1]

Advisors: Dr. Rama Valisetty[2], Dr. Avinash Dongare[1]

1. University of Connecticut, Storrs, CT
2. Army Research Lab, Aberdeen Proving Ground, MD

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Outline

1. Motivation
2. Need
3. Defects in Metals
4. Impact Loading conditions
5. Molecular Dynamics background
6. Specific Objective
7. Computational Details
8. Results
9. Future Work

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Motivation

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- Materials used for current armored applications possess high yield strengths; however, tend to fail in conditions of **extreme environments** (high velocity impact loading, temperatures, pressures, etc.)

- There exists a need to enhance the properties of next generation of armored materials
  - withstand multiple high velocity impacts
  - retain high yield strengths
  - lightweight

- The design of improved armored materials to be used in extreme environments require **enhanced performance** and **minimal degradation**

1. National Research Council. *Opportunities in Protection Materials Science and Technology for Future Army Applications.* Washington, DC: The National Academies Press, (2011)

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Need

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- Microstructure, chemistry, deformation behavior, degradation behavior all play an important role in the impact (shock) failure of metallic materials.

- For a material under impact loading, failure at the macroscale has been observed to be due to the micromechanical response at the atomic scale, where **nanovoids are generated and coalesce** to contribute to the cracking and subsequent failure of the material.

- In metals, the mechanical behavior is largely determined by the **evolution of defects (twins, dislocations, stacking faults, voids, etc.).**

Evolution of defect structures determined by a number of factors:

- Microstructure
- Loading conditions
- Temperature of the system
- Pressures

- A need to examine the **contribution of the evolution of defect structures to the failure response in metallic systems under impact loading**

2. A. M. Dongare, B. LaMattina, and A. M. Rajendran, Atomic Scale Studies of Spall Behavior in Single Crystal Cu, *Procedia Engineering* **10**, 3636 (2011).

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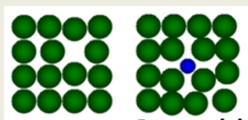
Defects in metallic materials

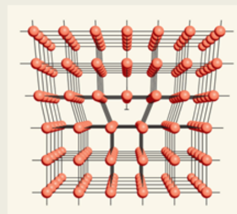
Metallic materials contain crystal-like structures where atoms are arranged in a certain orientation, then repeated throughout the material

A number of different types of defects located within crystal structure:

- -Point defects: interstitials, vacancies
- -1-D (linear): **dislocations**
- -2-D (planar): stacking faults
- -3-D (bulk): voids, impurities

Plasticity within deformed materials due to glide of dislocations throughout material





Example of Dislocation

Dislocation Type
Perfect
Shockley Partial
Stair-rod
Hirth
Frank
Twin

Dislocation Types

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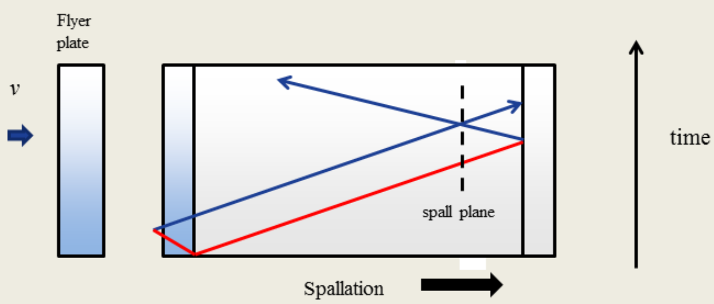
Impact Loading



- Experimentally impact loading achieved through plate impact or laser pulse to study shock response of materials.
- Impact generates compressive waves in the flyer plate and target.
- Compressive waves reflect from free surfaces as tensile waves that interact .
- Nucleation of voids, growth, and coalescence to form microscopic cracks and ultimately failure (Spallation).

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Molecular Dynamics

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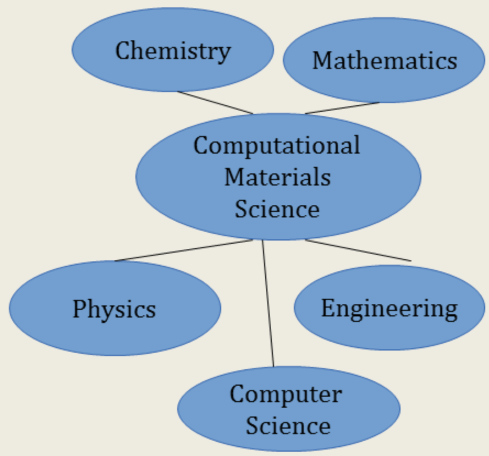
- The time and length scales for deformation phenomena (dislocation glide, void nucleation, spall failure, etc.) occurs at the atomic scale.

- Need to utilize computational modeling to view the microstructure as it is deforming.

- Molecular Dynamics (MD) simulations provide the capability to simulate a system of atoms under shock loading.



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Molecular Dynamics

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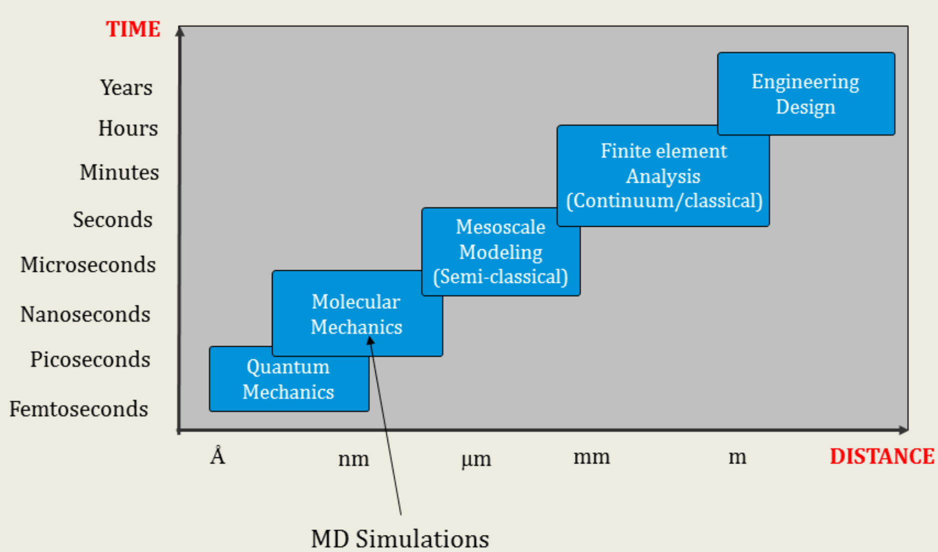

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Objective

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Objective: Investigate the effects of the evolution of defect densities on the failure of FCC metallic materials

- Run large scale shock loading MD simulations for various metallic materials (Single crystal Al, Cu)
- Identify and characterize various types of dislocations present through simulation using *CrystalAnalysis Tool*
- Investigate the relationship between failure, defect evolution, defect type, and other important factors:
  - Material type
  - Microstructure
  - Loading conditions

2. A.Stukowski and K. Albe, Extracting dislocations and non-dislocation crystal defects from atomistic simulation data, *Modelling Simul. Mater. Sci. Eng.* **18**, 085001 (2010)

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Computational Details

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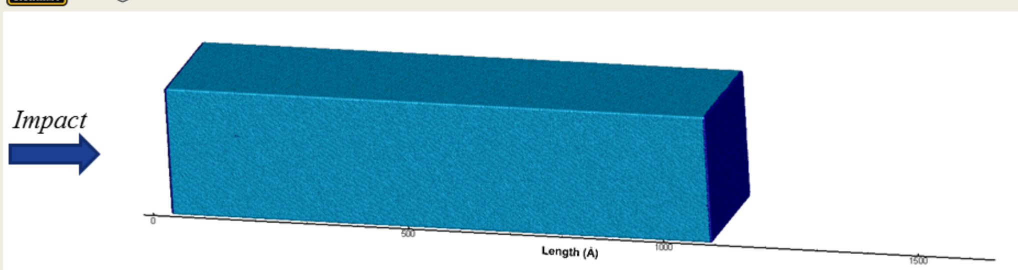

- Create a rectangular box system (long in impact direction) consisting of same type of atoms
- Designate first 3 nm of system as piston
- Provide the atoms in the piston region a constant impact velocity (1 km/s) for a given duration (10 ps)
- Release impact and observe the system evolve as the shock waves travel and reflect within the system
- Post Processing: Characterize different types of dislocations within system

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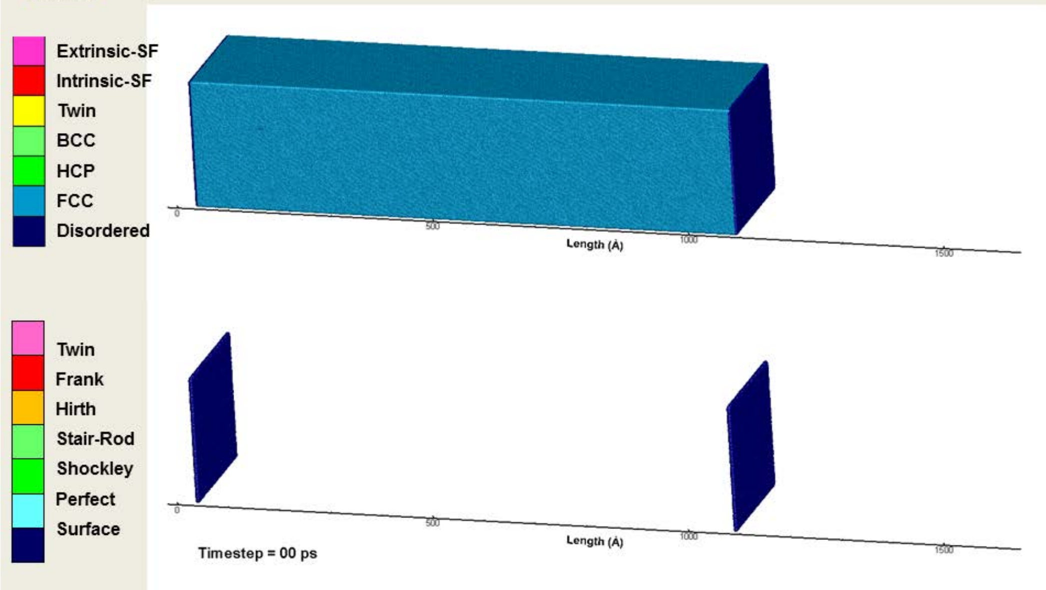
Single Crystal Copper



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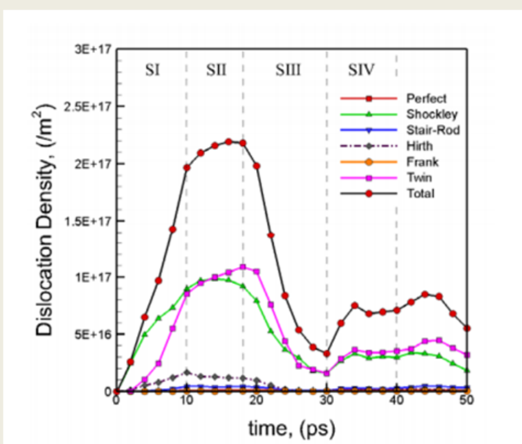
Dislocation Density-Cu



An increase in dislocation density is observed under the propagation of the compressive shock wave, followed by a decrease in density under the propagation of the reflected tensile wave.

The dislocation density is increased after the nucleation of voids.

$$\textit{Dislocation Density} = \frac{\textit{Dislocation Length}}{\textit{Volume of system}}$$

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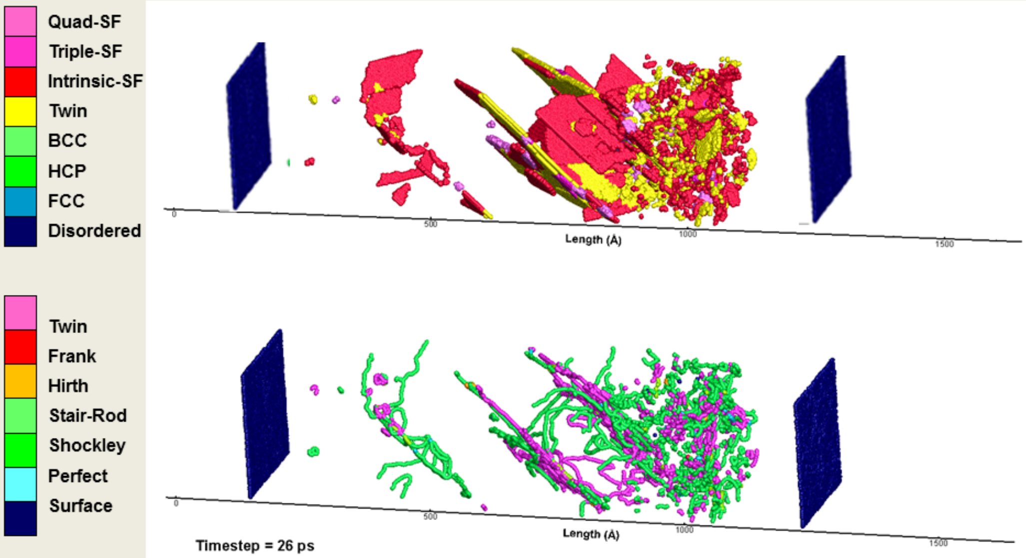
Results



Twinning and shockley dislocations are seen to be dominant dislocations during onset of failure.

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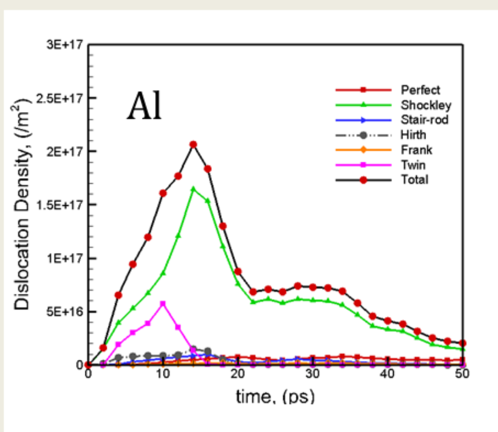
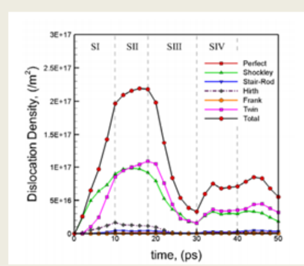
Dislocation Density-Al



The evolution trend for the total dislocation density is shown to be similar as the Cu system.

Less twinning is observed
→ due to high stacking fault energy (SFE) as compared to Cu

Cu →



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Conclusions

ARL

- MD simulations have been run for single crystal Cu and Al under shock loading simulations

- Dislocations and defects identified and characterized

- Same trend observed for total dislocation density evolution in both systems

- Twinning seen to be one of dominant dislocations in Cu, but not in Al
    - Observed in literature as well

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Future Work

ARL

Run shock loading simulations and extend dislocation analysis for:

- Different materials and crystal structures (HCP, etc.)

- Larger systems (>1 billion atoms)

- Different loading conditions (impact velocity, orientation, temperature, etc.)

- Different microstructures (nanocrystalline, etc.)

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Human Research & Engineering Directorate (HRED)

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Effects of Source Accuracy on Present and Absent Targets and Foils

Samantha Harper
University of Delaware
August 7, 2015

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Outline

ARL

1. Background
2. Study: Method and Results
3. My Project
    1. Method
    2. Results
4. Conclusions and Future Directions

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Introduction

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- Intelligence Analysis
- Trust
- Eye Tracking
  - Observe search patterns
  - Insight into the decision making process
  - Examine which types of information are more useful than others

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Methodology

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- Participants: 13 ARL employees
- 96 scenes: 4 High Value Targets (HVTs) and 4 Foils

Independent variables:

- Intel Source Accuracy: 90% vs. 60%
- HVT Volume: Number of HVTs described at once (1, 2 or 4)

Dependent variables:

- Decision Accuracy
- Ratings of Difficulty, Confidence, and Trust
- Eye movements: number of fixations

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Hypotheses

Trust:

- Participants will learn that one source is more accurate than the other and trust the accurate source more

Eye tracking:

- Individuals will look more often at absent High Value Targets (HVTs) with the 60% Intel Source than the 90% Intel Source
- Individuals will look at absent HVTs and Foils the same amount with the 90% Intel Source

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Procedure

Trial:

- Intel Screen
- Search Screen
- Questionnaire Screen
- Feedback Screen

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Intel Screen

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Time: 120

James 

1. Present: Blue shirt, Khaki pants

2.Absent: Light hair, Dark jacket

3.Absent: Black top, Wearing a backpack

4. Present: Dark hair, White shirt

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Search Screen

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1 2 3 4

Absent HVTs:

Submit

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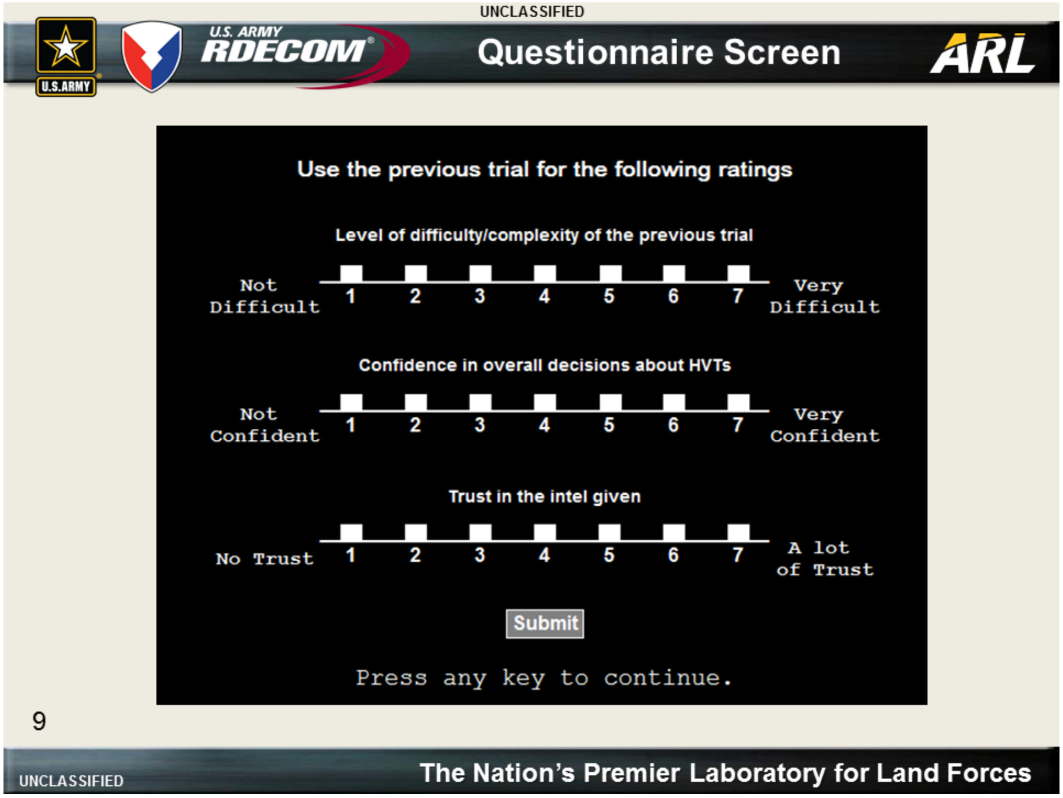

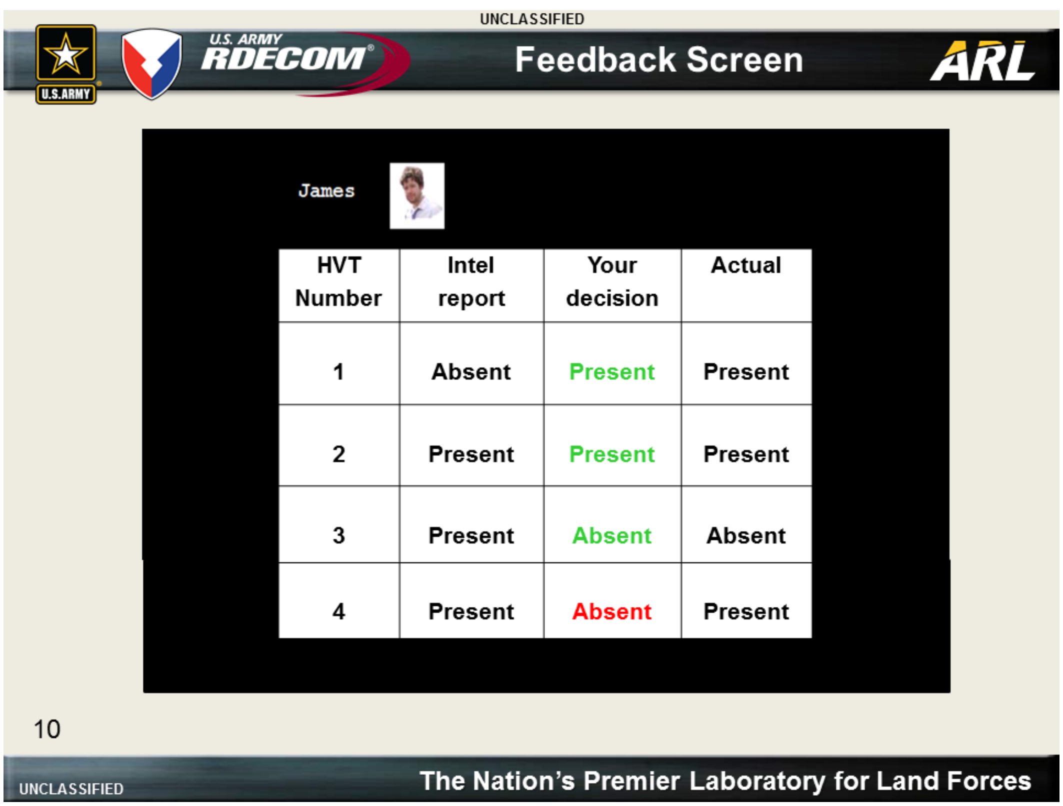

HVT Number	Intel report	Your decision	Actual
1	Absent	Present	Present
2	Present	Present	Present
3	Present	Absent	Absent
4	Present	Absent	Present

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Trust Results

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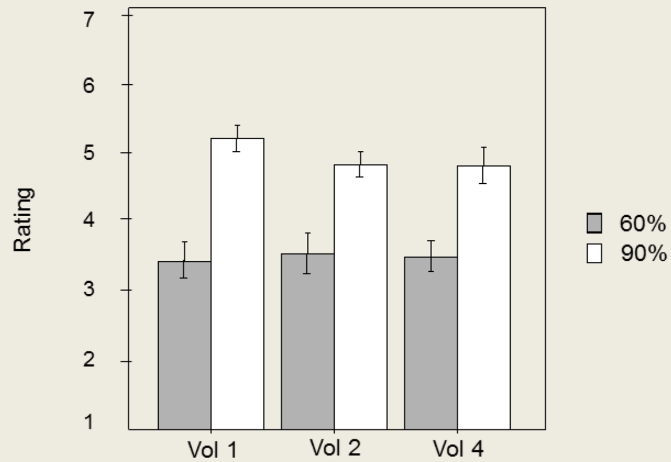

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Defining ROIs

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•Created boundaries for the regions of interest (ROIs)

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Data Cleaning

0.399107	1.200812	0.615815	0.416071	2.820447	638.1812	0	-1	-1	-1	-1	-1	-1	4
0.341242	1.148248	0.615944	0.415462	2.731251	637.6979	0	0.337211	0.95742	0.447937	0.393295	2.463784	637.3649	0
0.362308	1.162234	0.61597	0.416971	2.714465	637.6932	0	0.325686	0.981632	0.447811	0.392575	2.494111	637.215	0
0.36532	1.162747	0.615991	0.41606	2.724448	637.5387	0	-1	-1	-1	-1	-1	-1	4
0.351972	1.152048	0.615936	0.415874	2.673703	637.6303	0	0.315136	0.950809	0.447549	0.392297	2.391842	637.215	0
-1	-1	-1	-1	-1	-1	4	0.322231	0.957948	0.44741	0.392033	2.384853	637.215	0
0.357837	1.178212	0.615846	0.415975	2.699876	637.6279	0	0.332479	0.97971	0.44738	0.391781	2.41849	637.215	0
0.363289	1.174258	0.615963	0.415749	2.672094	637.3994	0	0.340625	0.991723	0.448685	0.391429	2.425043	646.5746	0
0.371643	1.178315	0.616081	0.41539	2.693588	637.3993	0	0.367049	0.962162	0.445899	0.392504	2.449576	646.5746	0
0.36977	1.175741	0.616213	0.415127	2.655173	637.3993	0	-1	-1	-1	-1	-1	-1	4
0.35907	1.163571	0.616409	0.414275	2.672136	637.452	0	0.315665	0.91712	0.447582	0.391171	2.352491	646.5706	0
-1	-1	-1	-1	-1	-1	4	0.327754	1.007869	0.447846	0.390942	2.457174	637.0695	0
0.37352	1.173888	0.616754	0.413741	2.738423	637.452	0	0.34441	1.100907	0.447995	0.391331	2.691353	637.0735	0
0.3652	1.165525	0.616958	0.414169	2.646918	637.4495	0	0.302761	0.912321	0.448284	0.38964	2.208156	637.0654	0
0.368778	1.180514	0.617194	0.414003	2.65631	637.4495	0	0.310085	0.949147	0.448501	0.389448	2.341266	637.0653	0
0.354733	1.144357	0.617463	0.413774	2.631077	637.4495	0	0.306499	0.928804	0.448779	0.389156	2.292798	637.0652	0
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0.37332	1.180832	0.617843	0.413535	2.667229	637.4494	0	0.347354	1.00938	0.449227	0.388855	2.510455	637.0652	0
0.370346	1.168792	0.617231	0.413641	2.663382	643.5607	0	-1	-1	-1	-1	-1	-1	4
0.362044	1.18501	0.617964	0.41367	2.657696	637.4495	0	0.290035	0.887654	0.450182	0.389007	2.211987	643.4362	0
0.363189	1.17779	0.618039	0.413749	2.664907	636.202	0	0.345525	0.979691	0.447504	0.390441	2.466768	644.9291	0
0.3739	1.181429	0.617914	0.41315	2.685086	636.1998	0	0.289821	0.92661	0.450203	0.389155	2.251671	644.9208	0
0.366917	1.172769	0.617653	0.414151	2.628328	636.1973	0	0.307398	0.924646	0.450001	0.389464	2.260811	644.9209	0
0.351081	1.131776	0.617439	0.413683	2.612685	635.9223	0	0.297047	0.934027	0.449725	0.389852	2.289969	644.921	0
0.348727	1.175542	0.617058	0.414702	2.633388	635.9199	0	0.289648	0.915308	0.449386	0.390242	2.210931	644.921	0
0.371932	1.158071	0.616798	0.414204	2.673497	635.6425	0	-1	-1	-1	-1	-1	-1	4
0.355172	1.146283	0.616488	0.41421	2.618819	635.5737	0	0.267625	0.915382	0.448716	0.390554	2.162024	644.9211	0
0.353219	1.141294	0.616266	0.414206	2.601598	635.5322	0	-1	-1	-1	-1	-1	-1	4
0.36348	1.166076	0.616157	0.414938	2.622056	635.4995	0	-1	-1	-1	-1	-1	-1	4
0.365225	1.162257	0.616162	0.415024	2.640307	635.4995	0	0.296305	0.927897	0.447954	0.390816	2.2569	641.7747	0
0.364207	1.149339	0.616238	0.415241	2.621223	635.4995	0	0.32193	1.019633	0.446978	0.391823	2.463782	641.7787	0
0.366712	1.179521	0.616305	0.415527	2.651641	635.4996	0	0.350325	1.053155	0.446034	0.392812	2.572191	641.7827	0
0.369573	1.168785	0.616319	0.415664	2.650174	635.6464	0	0.34202	1.09653	0.447197	0.392864	2.647437	634.9399	0
0.374087	1.162789	0.616294	0.414872	2.685022	635.7286	0	-1	-1	-1	-1	-1	-1	4
0.3442	1.123252	0.616195	0.415465	2.582196	635.7261	0	0.314543	0.976003	0.447076	0.391233	2.323225	634.9319	0
0.371128	1.152266	0.616072	0.41453	2.6537	635.8524	0	-1	-1	-1	-1	-1	-1	4
0.351393	1.150845	0.615883	0.414954	2.605016	635.8499	0	0.33957	1.06291	0.446807	0.392105	2.535411	634.9399	0
0.35358	1.153353	0.615708	0.414531	2.634429	635.8499	0	0.320646	1.019617	0.446592	0.391075	2.445532	635.2339	0
0.392035	1.150454	0.615023	0.414028	2.658483	635.8498	0	0.362452	0.887761	0.445871	0.390588	2.155565	635.0798	0
0.533464	1.066242	0.613209	0.412032	2.706122	635.8137	0	0.565566	0.855246	0.444317	0.389286	2.337765	635.4763	0
0.62098	1.044893	0.611751	0.410561	2.674122	635.6754	0	0.644009	0.826073	0.443309	0.387934	2.297609	635.312	0
0.659543	0.984194	0.611372	0.411159	2.6234	635.6391	0	0.640118	0.882474	0.443111	0.388568	2.449974	635.3747	0
0.658953	0.97256	0.611397	0.411182	2.622357	635.7894	0	0.655827	0.836226	0.443061	0.388741	2.373406	635.4445	0

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Defining Gaze Position

- Averaged x gaze position of the left eye and right eye, and did the same for the y position
- Converted these data into pixels
- Used gaze data and ROI boundaries to determine if a fixation was in a ROI
- Calculated absent and present from the Intel's best guess

Foil1	Foil2	Foil3	Foil4	HVT1	HVT2	HVT3	HVT4
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
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FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

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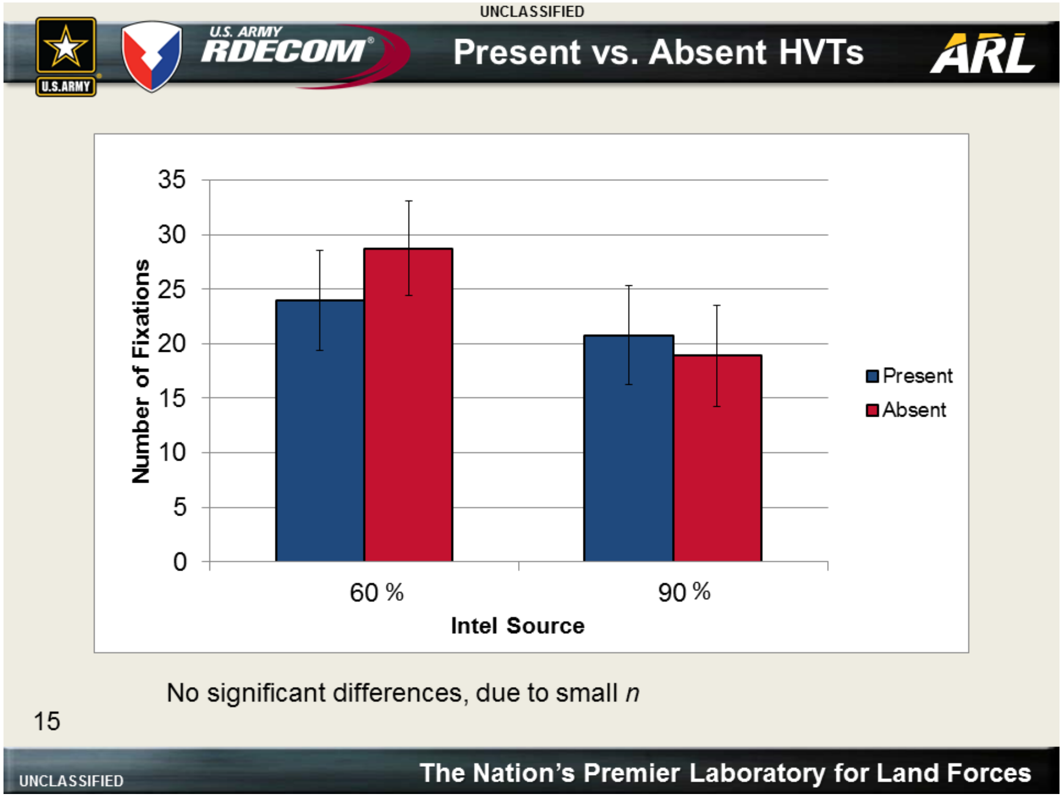
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Present vs. Absent HVTs
ARL
35
30
25
20
15
10
5
0
Number of Fixations
60 %
90 %
Intel Source
Present
Absent
No significant differences, due to small *n*
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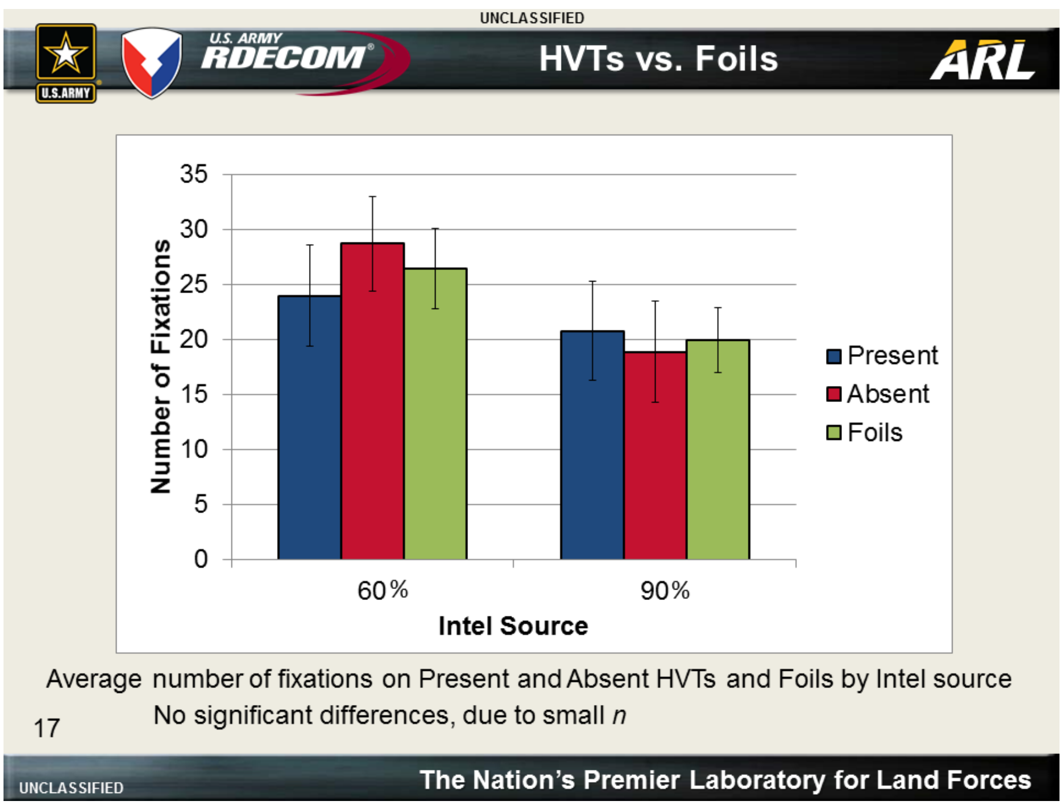
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U.S. ARMY
HVTs vs. Foils
ARL
35
30
25
20
15
10
5
0
Number of Fixations
60%
90%
Intel Source
Present
Absent
Foils
Average number of fixations on Present and Absent HVTs and Foils by Intel source
No significant differences, due to small *n*
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Heat Map

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Conclusions

Eye tracking:

- **No statistical significance found**
- **With the 60% Intel Source, participants looked more at absent HVTs than present HVTs**
- **With the 90% Intel Source, participants looked less at all ROIs, and looked at Foils and absent HVTs less than present HVTs**

Trust:

- **Participants trusted the 90% Intel Source**
- **Soldiers search more efficiently with trusted sources**

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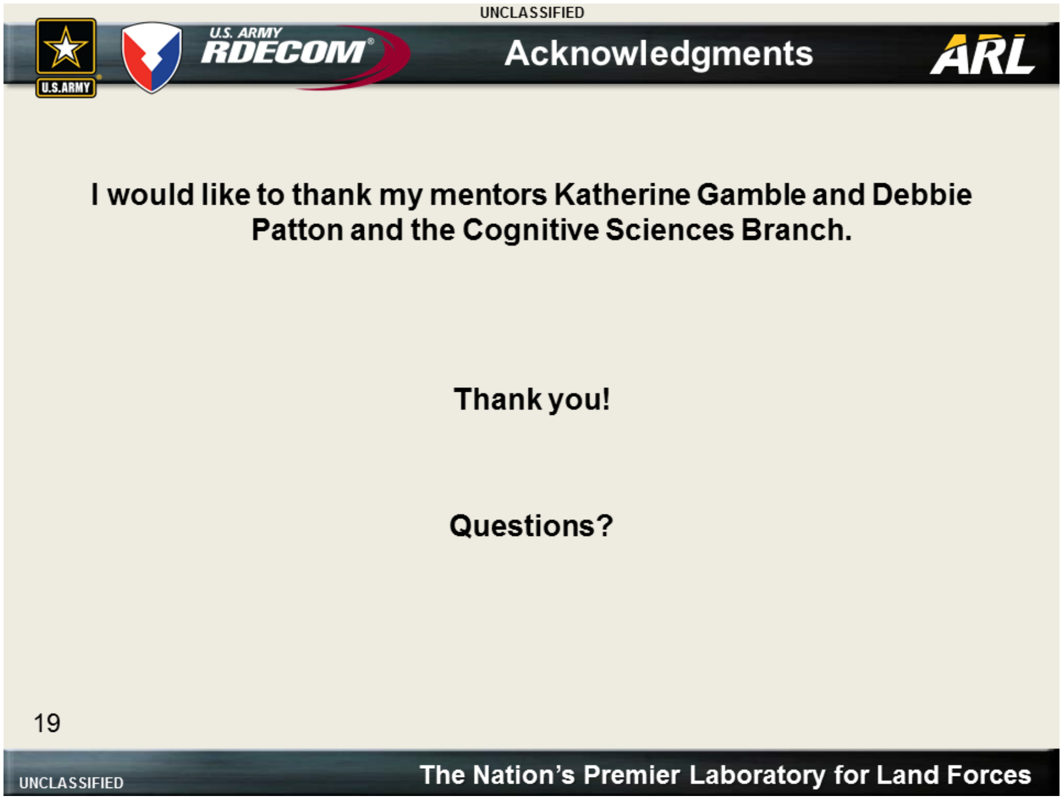
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Acknowledgments
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I would like to thank my mentors Katherine Gamble and Debbie Patton and the Cognitive Sciences Branch.
Thank you!
Questions?
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EFFECTS OF COGNITIVE FATIGUE ON HIGH INTENSITY CIRCUIT EXERCISE

Hope Davis, BA
Dismounted Warrior Branch

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Introduction

MY CONTRIBUTIONS:

- Data collection
- Formation of hypotheses
- Data reduction
- Statistical analysis

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Background

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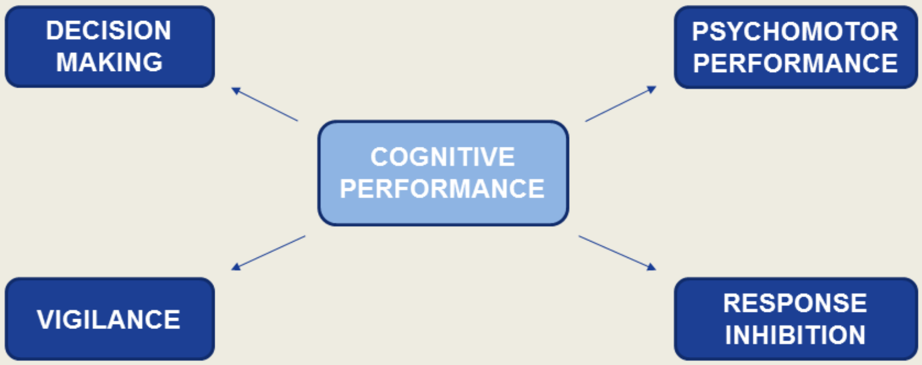

Friend et al., 2007; Wilson et al., 2013

Failures in cognitive performance can result in increased likelihood of friendly-fire incidents and collateral damage (Wilson et al., 2013).

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Background

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COGNITIVE FATIGUE

The psychophysiological response to prolonged exposure in a cognitively demanding task results in subjective feeling of "tiredness" and "lack of energy" (Marcora et al., 2009; Pageaux et al., 2014).

Cognitive fatigue can affect subsequent physical performance:

- Time to exhaustion/fixed power (Marcora et al., 2009).
- Timed task/fixed distance (Pageaux et al., 2014).

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Background

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WHY SHOULD WE CARE?

- With increasingly sophisticated communication devices, cognitive fatigue may continue to be a relevant issue for the Soldier.
- When cognitively fatigued individuals reach high levels of exertion, they are more likely to disengage from the physical task (Marcora et al., 2009; Pageaux et al., 2014).
- Soldiers must transition between physically demanding tasks for an extended amount of time, i.e., high intensity circuit training.

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Hypotheses

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1. Number of overall repetitions completed will be **lower** after completing a cognitively fatiguing task.
2. Time-on-task during the physical exercise will **decrease** after a vigilance task compared to the control task.
3. When separating the 20-minute physical task into quartiles (5-minute segments), time-on-task will be most affected in the **first period** when preceded by the cognitively fatiguing task.
4. Physiological measurements (oxygen uptake and caloric expenditure) will see **no change**.

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Methods

Seven male and 4 female participants (goal n =30) completed 2 sessions of a vigilance or video (control) task (50 minutes) followed by a timed (20 minute) circuit-workout.

Vigilance task

- low Go/ high No-Go (Marcora et al., 2009)

Video task (control)

- Documentary (Luxury Trains of the World) used in previous paradigms (Pageaux et al., 2014).

Physical Task

- 20 minutes, as many repetitions as possible
- Circuit of 5 pull-ups, 10 push-ups and 15 squats

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Methods

8

Methods

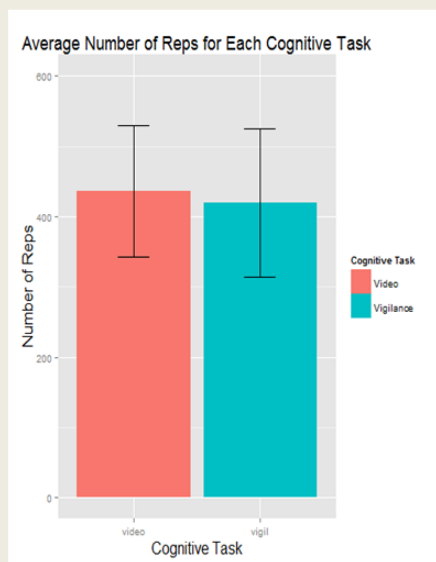
- Data Reduction
  - Total repetitions was calculated.
  - Time-on-task (TOT) was measured in seconds with video observation.
  - TOT was also separated into four 5-minute segments within the circuit exercise task to examine time effects of the vigilance task.
  - Mean value of oxygen uptake and caloric expenditure calculated.
- Statistical Analysis
  - Repeated measures t-tests determined differences between cognitive tasks for repetitions, TOT, and physiological measurements.
  - Repeated measures ANOVA examined effect of time and the vigilance task on TOT.

Results

REPS vs. COGNITIVE TASK

Contrary to the hypothesis, there was no significant difference in the total number of reps between cognitive tasks (p = 0.18).

Cognitive Task	Mean (Reps)	Standard Deviation
Video (control)	436	93
Vigilance task	420	106



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Results

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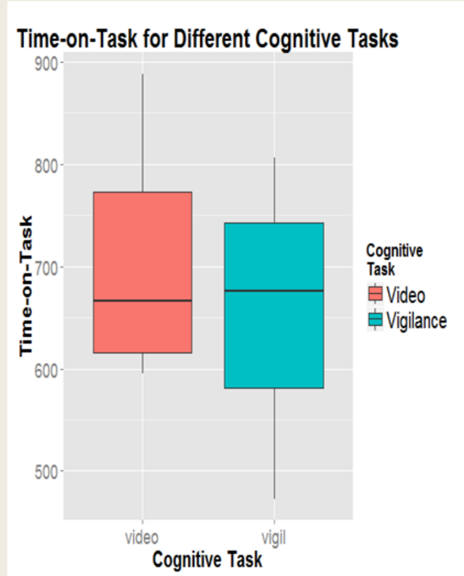
TIME ON TASK vs. COGNITIVE TASK

TOT values significantly decreased by 3% (37 seconds; $p < 0.029$) after a vigilance task compared to a control video.

	Cognitive Task	Mean (Seconds)	Standard Deviation
1	Video (control)	699.8348	100.0143
2	Vigilance	662.7567	108.4477



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Results

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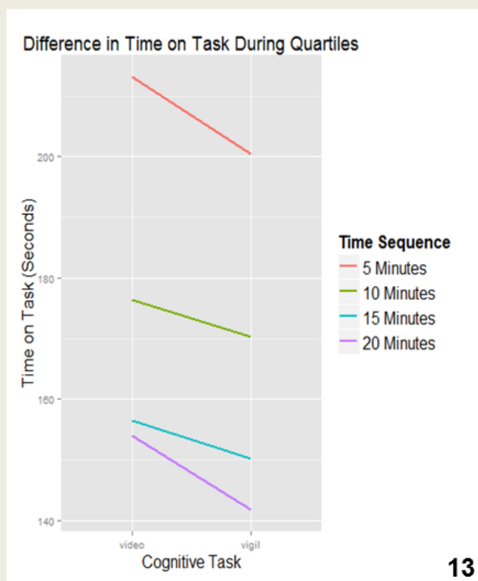
TIME ON TASK FOR QUARTILES

There is no interaction between the cognitive task and the quartile ($p = 0.97$).

There is a significant difference in the time on task between each quartile ($p < 0.005$).

There is no significant difference in time on task between cognitive tasks ($p = 0.143$).

Quartile	Mean (seconds)	Standard Deviation
1	206.8	27.2
2	173.3	31.5
3	153.4	28.2
4	147.8	31.4



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Results

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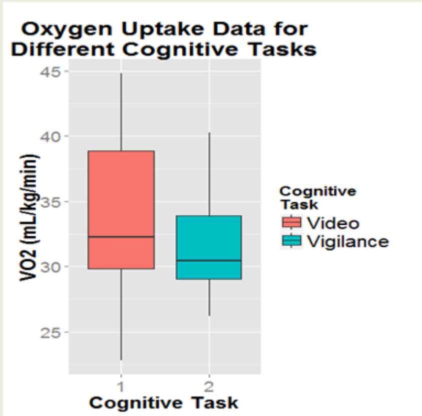
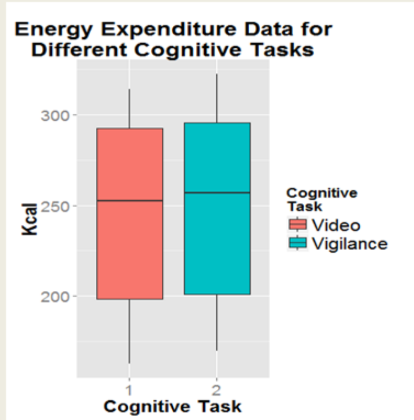
PHYSIOLOGICAL DATA



Task	Mean (mL/kg/min)	Standard Deviation
Video	34.3	6.2
Vigilance	32.5	4.9
P = 0.51		



Task	Mean (Kcal)	Standard Deviation
Video	246.4	57.6
Vigilance	248.3	55.6
P = 0.94		

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Discussion

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So far, the circuit task demonstrates that performance is decreased by 3%.

Similar to findings in past literature:

- 6% increase in timed run (Pageaux et al., 2014)
- 15% decrease in time to exhaustion (Marcora et al., 2009)

The discontinuous nature of the present study is potentially more operationally relevant than constant stretch-shortening-cycle tasks performed in previous studies.

Future Research

COGNITIVE PSYCHOLOGY

Dr. Head's ongoing study examines the effects of cognitive fatigue on subsequent marksmanship in Soldiers.

PHYSIOLOGY

1. Creating a technique to mitigate effects of cognitive fatigue in Soldiers in the field (automated devices).
2. Sex differences in response to stress (progesterone during menstrual cycle).
3. Changes in biomechanics/predisposition to injury.

16

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CITATIONS

Friedl, K. E., Grate, S. J., Proctor, S. P., Ness, J. W., Lukey, B. J., & Kane, R. L. (2007). Army research needs for automated neuropsychological tests: Monitoring soldier health and performance status. *Archives of Clinical Neuropsychology, 22*, 7-14.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Physiology, 106*, 857-864.

Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology, 114*, 1095-1105.

Wilson, K., Head, J., & Helton, W. S. (2013). Friendly fire in a simulated firearms task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57*, 1244-1248.

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Acknowledgements

The author wishes to acknowledge the mentorship of Dr. Matthew Tenan and Dr. James Head.

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Sensors and Electron Devices Directorate (SEDD)

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U.S. Army Research, Development & Engineering Command

Bio-Hybrid Fuel Cells for Waste Mitigation

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Marcus Benyamin
University of Maryland, College Park
Junior, Chemical Engineering & Mathematics

Mentors: Dr. David Mackie & Dr. Justin Jahnke
BioTechnology Branch

(U//FOUO) **07 August 2015**

Objective & Outline

Summary Objective: Design, build, and test a flowing vapor-fed bio-hybrid fuel cell system for wastewater treatment

- Introduction
  - Army Motivation
  - Direct Ethanol Fuel Cells and Bio-Hybrid Fuel Cells
- Design of System
  - Setup
  - Predictions and Testing
- Results
  - Kinetic data, flow rate data, and reactor model
  - Power vs. Voltage
  - Long-term operation of BHFC system
- Conclusions and Future Work

(U//FOUO)

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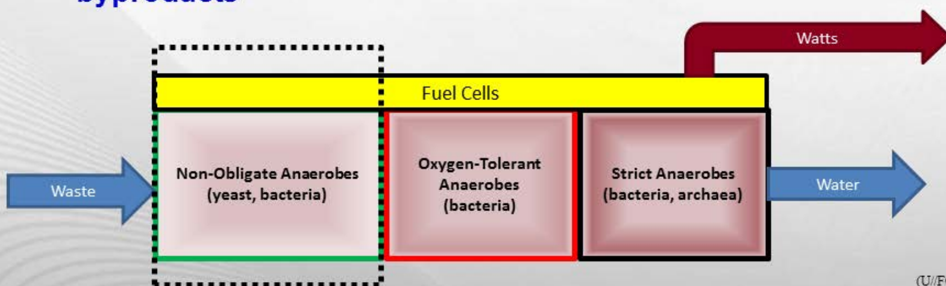
Army Motivation

- Waste to Water and Watts (WWW) for the Forward Operating Base (FOB)
  - Requirements: Small scale, mobility, stealth, low-energy
- Microbial Processing of food waste
  - Multi-stage processing generates clean water and chemicals/fuel as byproducts

Photo Credit: Karen Parrish, DoD



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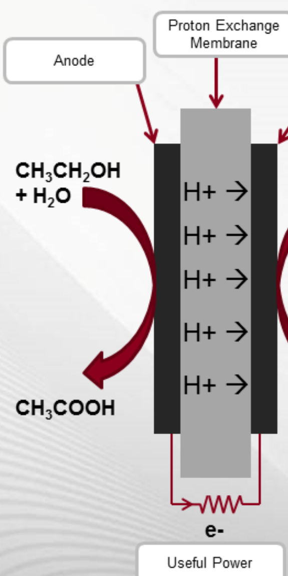
3

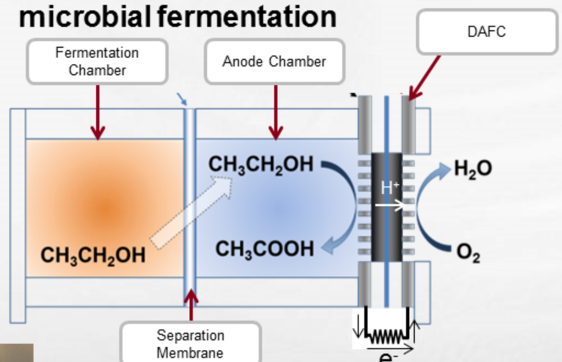
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Direct-Ethanol Fuel Cells (DEFCs) and the Bio-Hybrid Fuel Cell (BHFC)



Active Area: 2.68 cm^2

- Food waste/media poisons the fuel cell catalyst while acetate kills the microbial fermentation



Justin P. Jahnke, David M. Mackie, Marcus Benyamin, Rahul Ganguli, and James J. Sumner, Performance study of sugar-yeast-ethanol bio-hybrid fuel cells , *Proc. SPIE* 9493, Energy Harvesting and Storage: Materials, Devices, and Applications VI, 949303 (May 15, 2015); doi:10.1117/12.2176465;

David M. Mackie, Sanchao Liu, Marcus Benyamin, Rahul Ganguli, James J. Sumner, Direct utilization of fermentation products in an alcohol fuel cell, Journal of Power Sources, Volume 232, 15 June 2013, Pages 34-41, ISSN 0378-7753, http://dx.doi.org/10.1016/j.jpowsour.2013.01.077.)

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4

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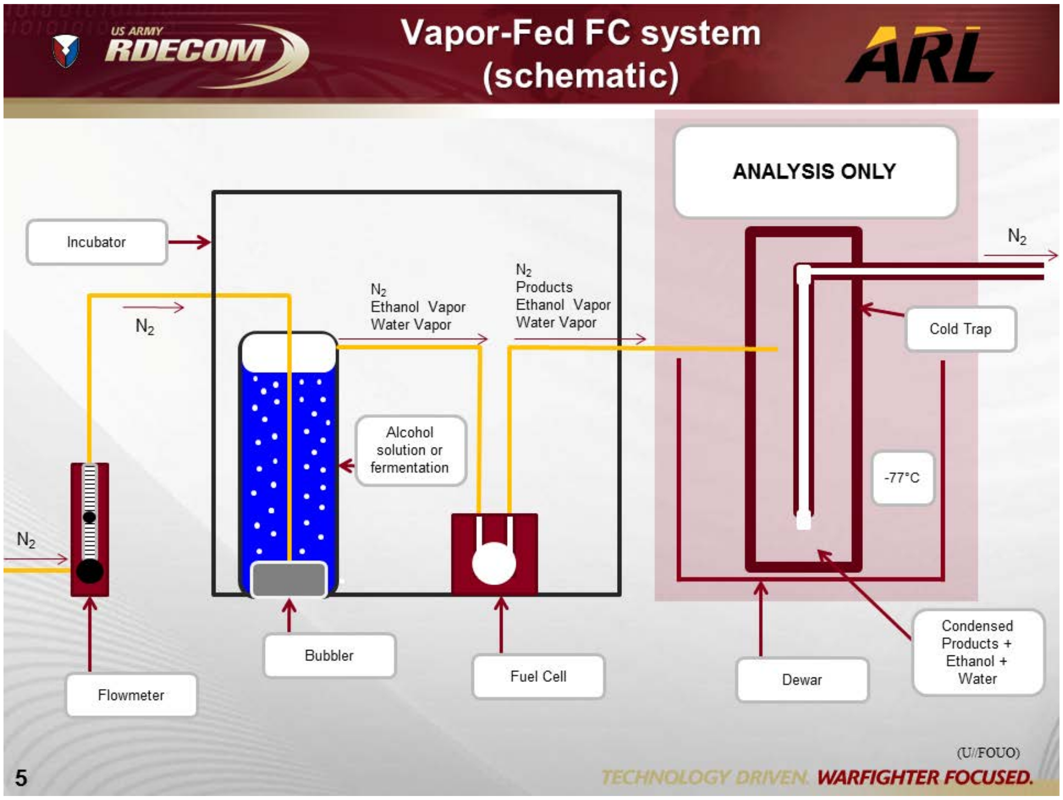
US ARMY RDECOM
Vapor-Fed FC system (schematic)
ARL
ANALYSIS ONLY
Incubator
N_2
N_2
Ethanol Vapor
Water Vapor
N_2
Products
Ethanol Vapor
Water Vapor
N_2
Cold Trap
Alcohol solution or fermentation
-77°C
N_2
Condensed Products + Ethanol + Water
Bubbler
Fuel Cell
Dewar
Flowmeter
(U//FOUO)
5
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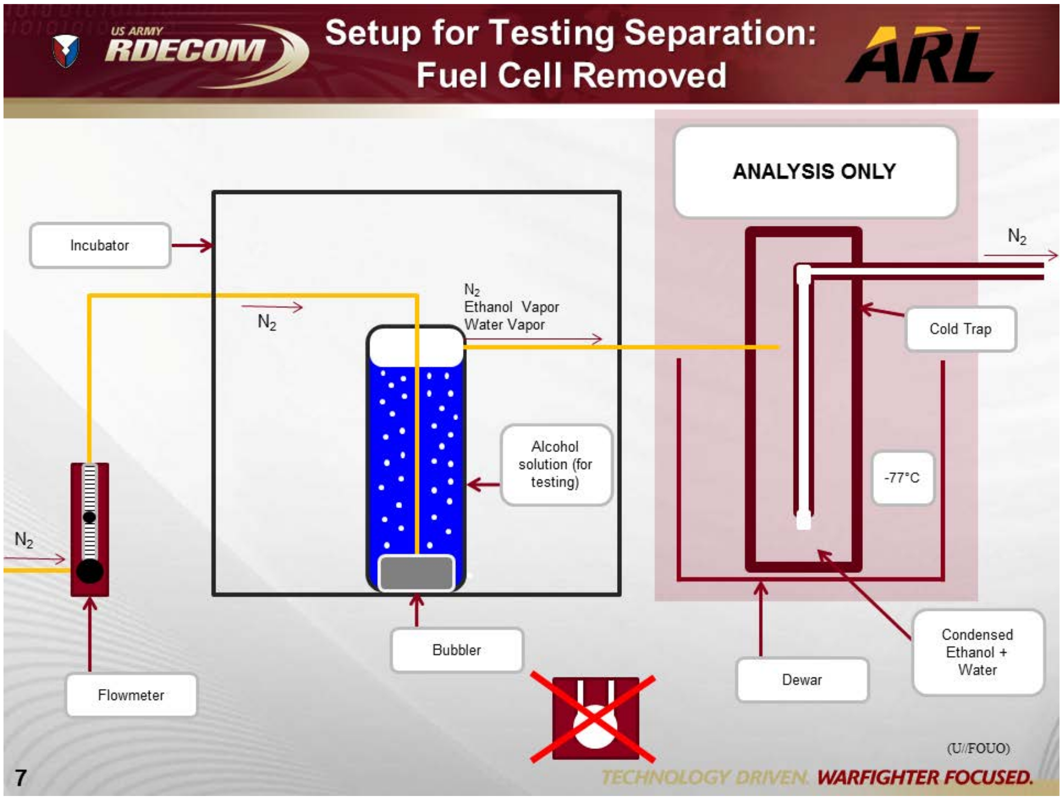
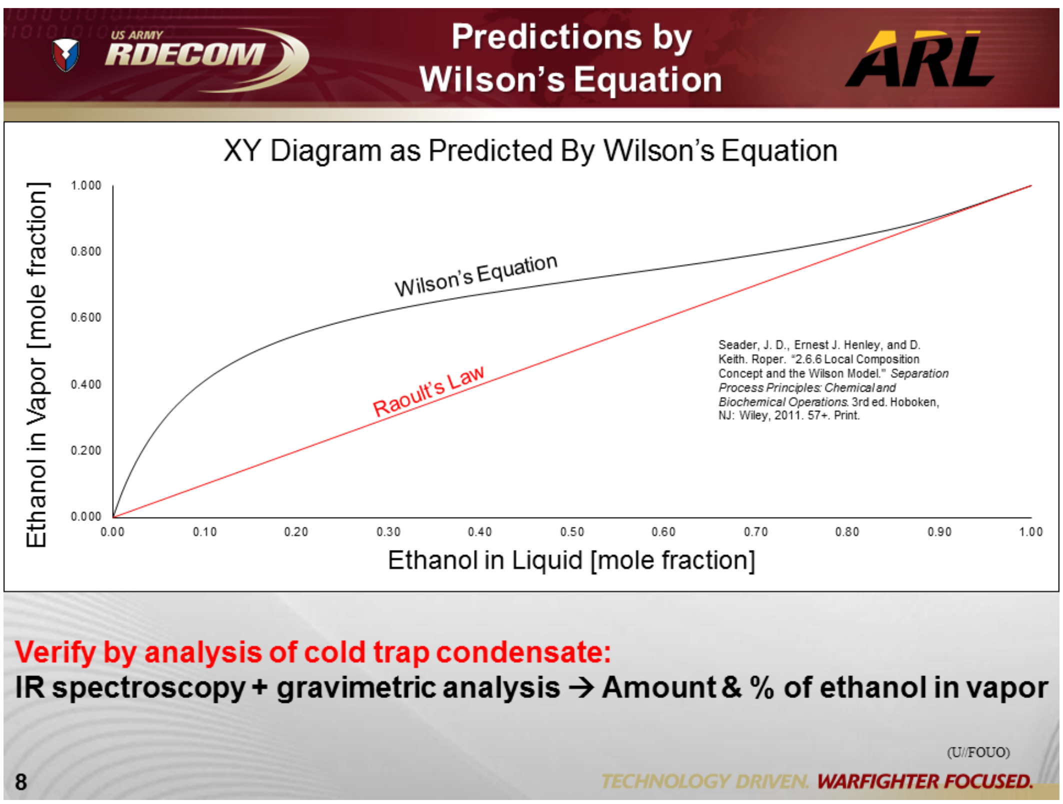
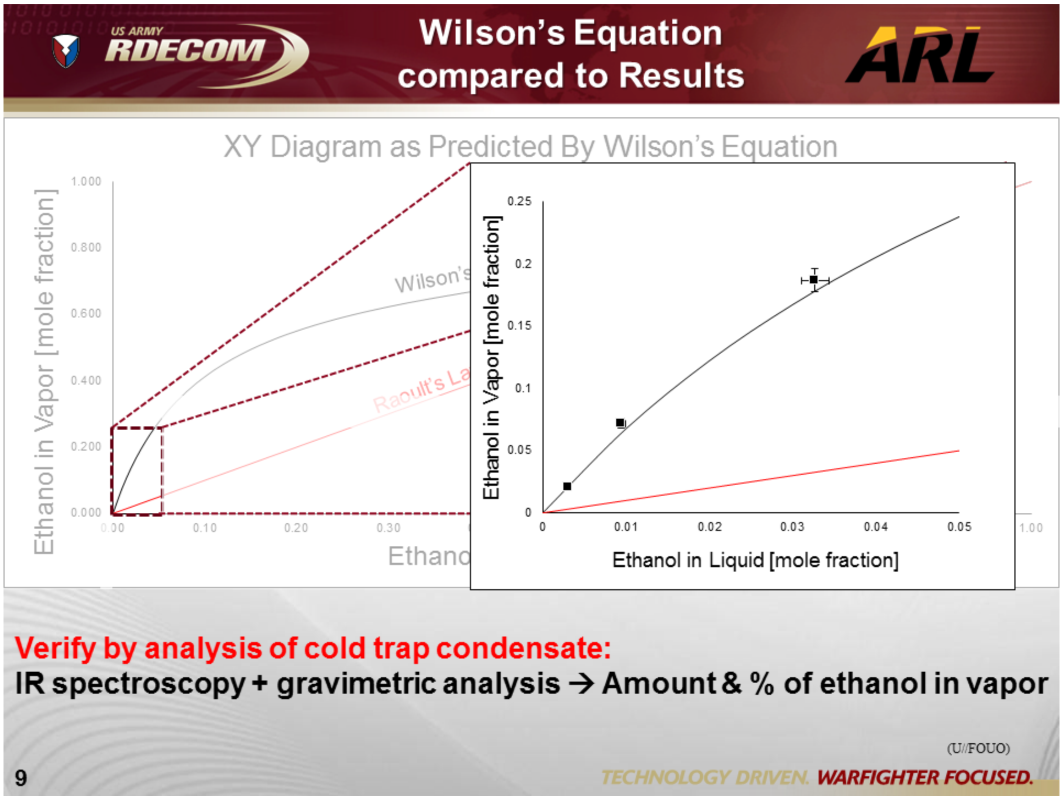
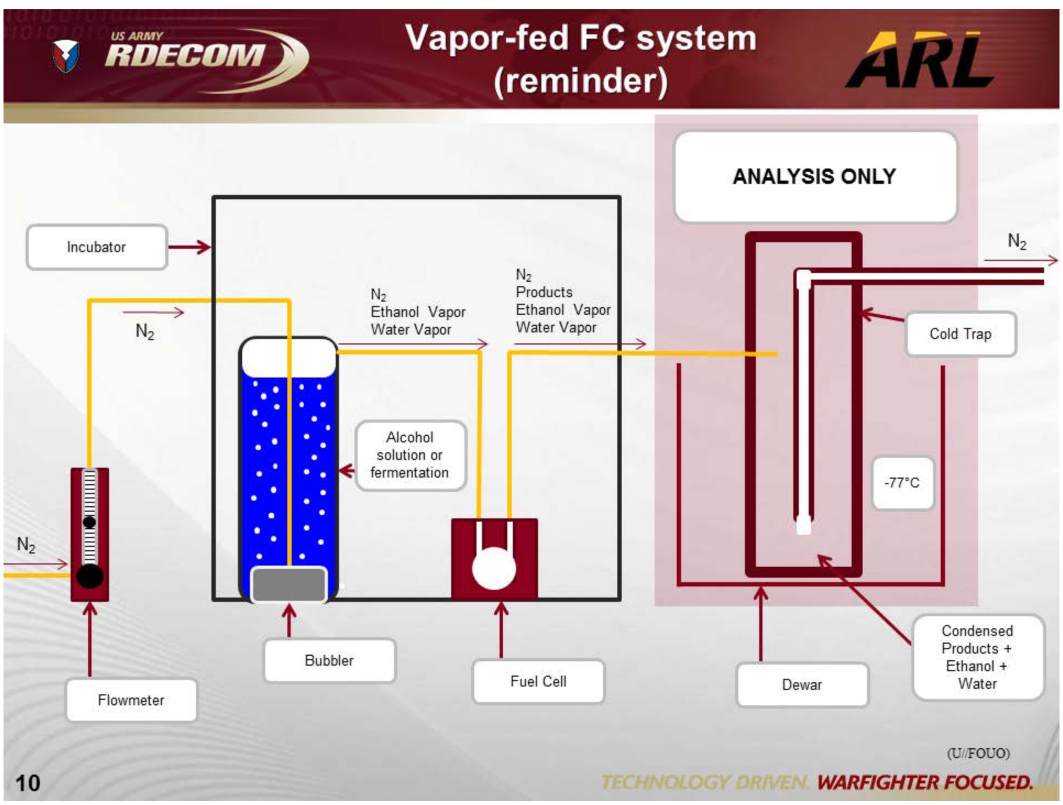
US ARMY RDECOM
Vapor-Fed FC system (reality)
ARL
BOEKEL
Boekel Scientific
(U//FOUO)
6
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.


US ARMY
RDECOM
Setup for Testing Separation: Fuel Cell Removed
ARL
ANALYSIS ONLY
Incubator
N_2
N_2
Ethanol Vapor
Water Vapor
N_2
Cold Trap
Alcohol solution (for testing)
-77°C
N_2
Bubbler
Dewar
Condensed Ethanol + Water
Flowmeter
(U//FOUO)
7
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.


US ARMY
RDECOM
Predictions by Wilson's Equation
ARL
XY Diagram as Predicted By Wilson's Equation
Ethanol in Vapor [mole fraction]
Ethanol in Liquid [mole fraction]
Wilson's Equation
Raoult's Law
Seader, J. D., Ernest J. Henley, and D. Keith. Roper. "2.6.6 Local Composition Concept and the Wilson Model." Separation Process Principles: Chemical and Biochemical Operations. 3rd ed. Hoboken, NJ: Wiley, 2011. 57+. Print.
Verify by analysis of cold trap condensate:
IR spectroscopy + gravimetric analysis → Amount & % of ethanol in vapor
(U//FOUO)
8
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.





Approved for public release; distribution is unlimited.

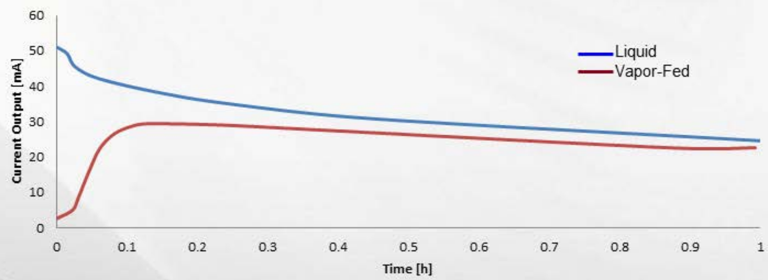
Product Analysis & I-t curves

Combining analysis of condensate and electrochemical data, we can:

-Calculate a mass balance for the fuel cell to determine crossover losses

-Examine product distribution at varied voltages and temperatures

-Determine conversions for ethanol



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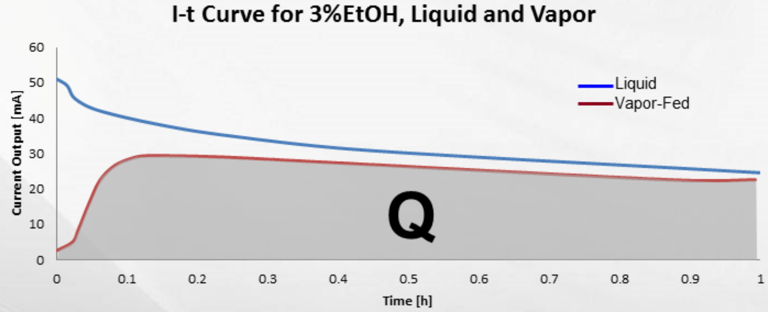
Product Analysis & I-t curves

Combining analysis of condensate and electrochemical data, we can:

-Calculate a mass balance for the fuel cell to determine crossover losses

-Examine product distribution at varied voltages and temperatures

-Determine conversions for ethanol



Q → # electrons → # moles reacted → % conversion & mass balance

Most of performance data can be taken with only the electrical measurements.

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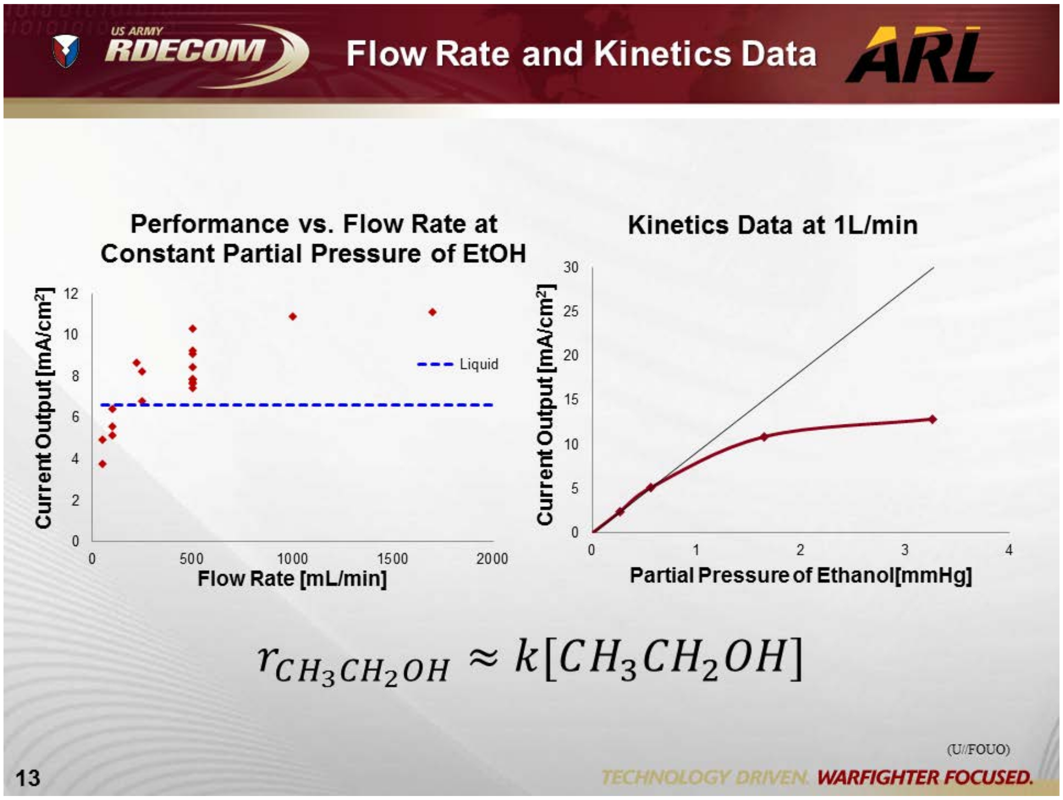
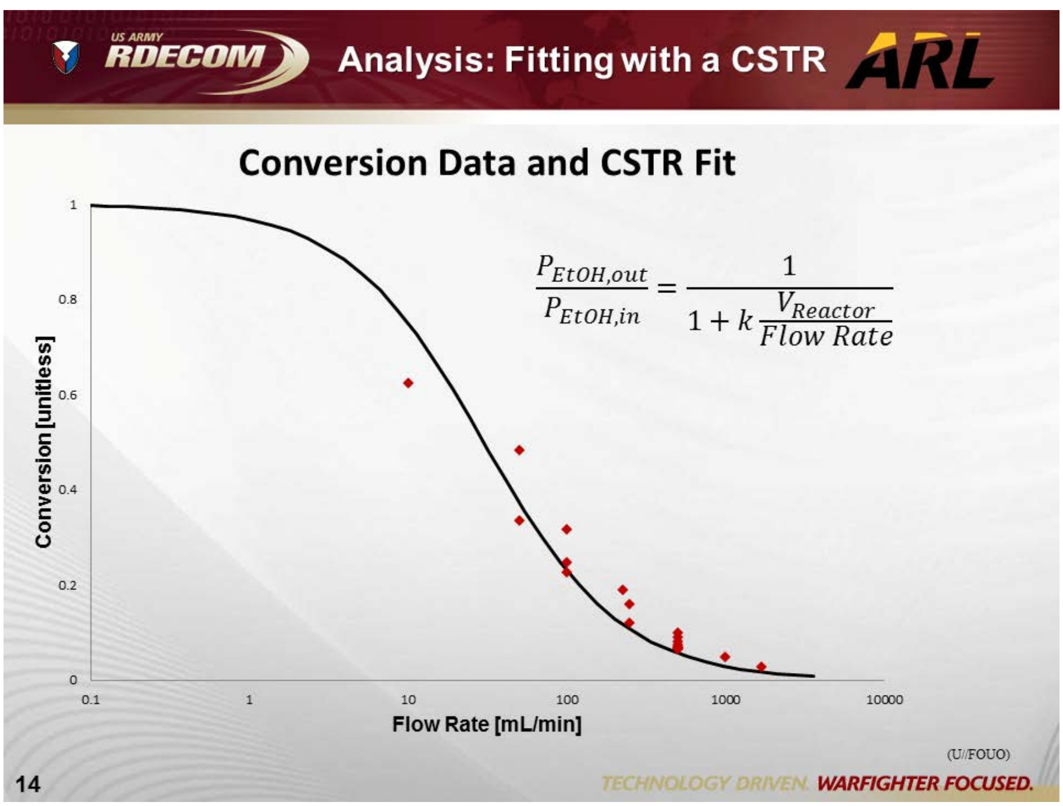
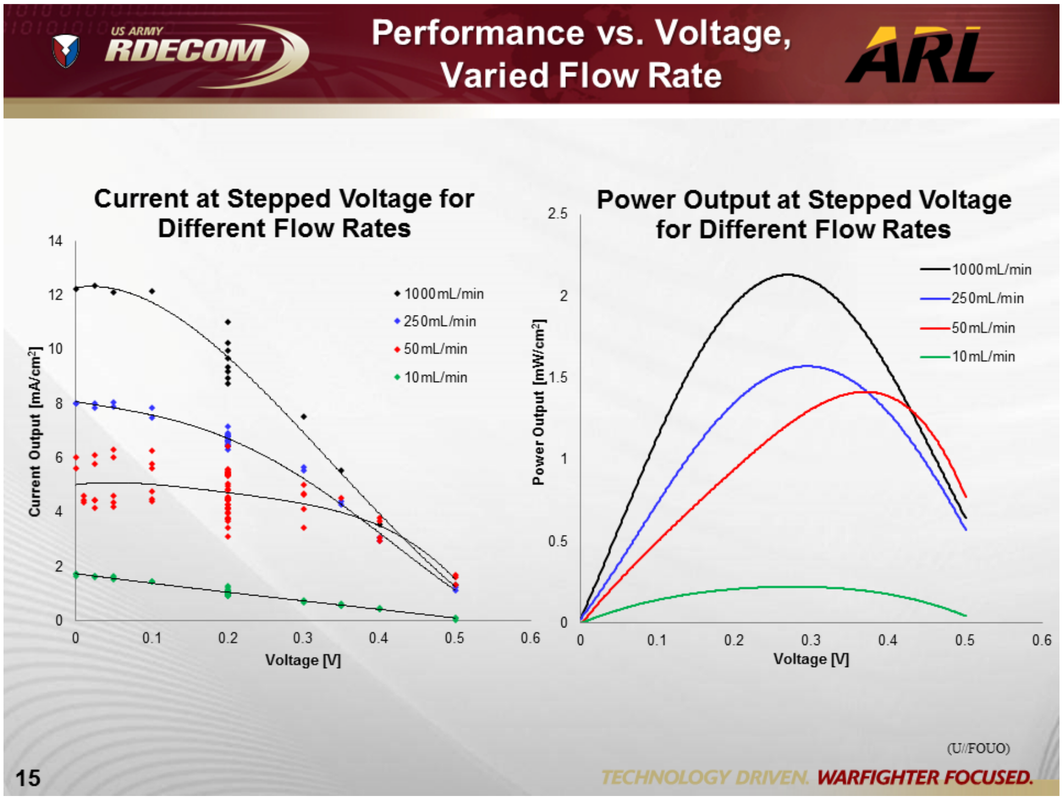
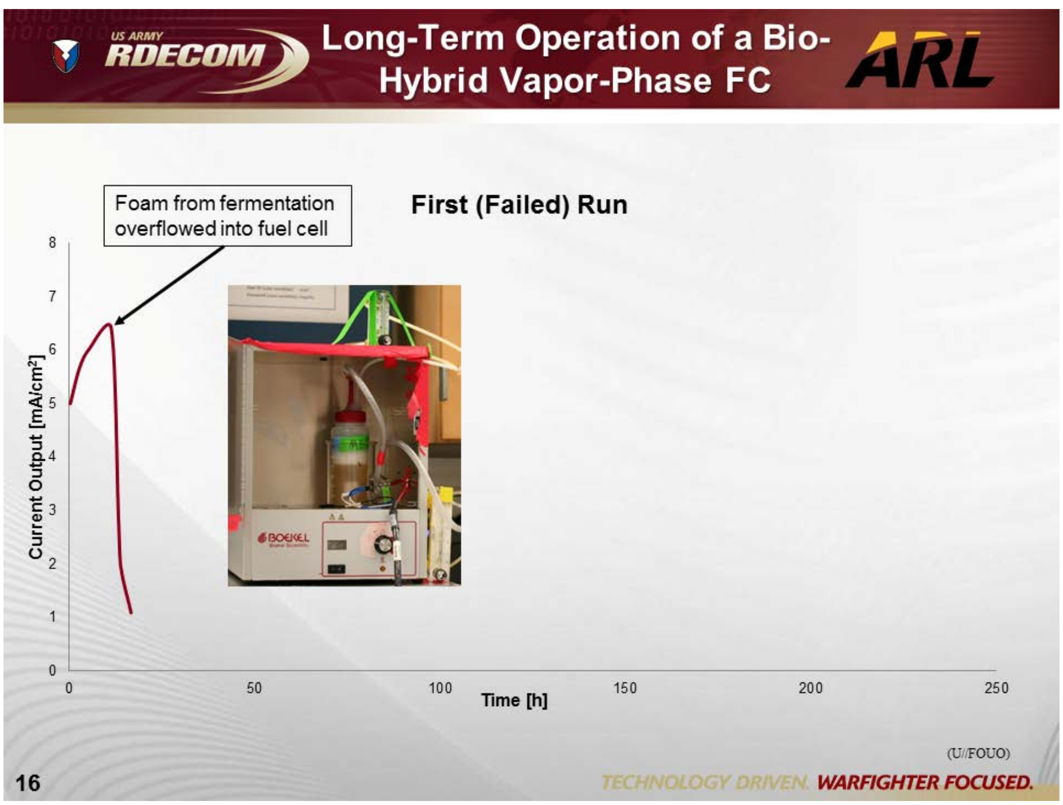

US ARMY
RDECOM
Flow Rate and Kinetics Data
ARL
Performance vs. Flow Rate at Constant Partial Pressure of EtOH
Current Output [mA/cm²]
Flow Rate [mL/min]
Liquid
Kinetics Data at 1L/min
Current Output [mA/cm²]
Partial Pressure of Ethanol[mmHg]
$r_{CH_3CH_2OH} \approx k[CH_3CH_2OH]$
(U//FOUO)
13
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.


US ARMY
RDECOM
Analysis: Fitting with a CSTR
ARL
Conversion Data and CSTR Fit
$\frac{P_{EtOH,out}}{P_{EtOH,in}} = \frac{1}{1 + k\frac{V_{Reactor}}{Flow\ Rate}}$
Conversion [unitless]
Flow Rate [mL/min]
(U//FOUO)
14
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.


US ARMY
RDECOM
Performance vs. Voltage, Varied Flow Rate
ARL
Current at Stepped Voltage for Different Flow Rates
Current Output [mA/cm²]
Voltage [V]
1000mL/min
250mL/min
50mL/min
10mL/min
Power Output at Stepped Voltage for Different Flow Rates
Power Output [mW/cm²]
Voltage [V]
1000mL/min
250mL/min
50mL/min
10mL/min
(U//FOUO)
15
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.


US ARMY
RDECOM
Long-Term Operation of a Bio-Hybrid Vapor-Phase FC
ARL
Foam from fermentation overflowed into fuel cell
First (Failed) Run
Current Output [mA/cm²]
Time [h]
BOEKEL
(U//FOUO)
16
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Long-Term Operation of a Bio-Hybrid Vapor-Phase FC

ARL

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Conclusions and Future Work

ARL

Conclusions:

- **Built and tested a novel vapor-fed bio-hybrid fuel cell**
- **Performance is comparable to that of liquid-fed fuel cell**
- **Flow rate and performance data fit to CSTR reactor model**
- **Optimal voltage for peak power output depends on flow rate**
- **Extended BHFC run time from <24 h to 2 weeks**

Future Work:

- **Kinetics and product distribution at elevated temperature**
- **Lower-energy vapor generation**
- **Microbial consortia to digest simulated food waste**

Acknowledgements:

- **Dr. David Mackie and Dr. Justin Jahnke**
- **Dr. Jim Sumner and the Biotechnology Branc**
- **ARL, ASEE, and CQL**

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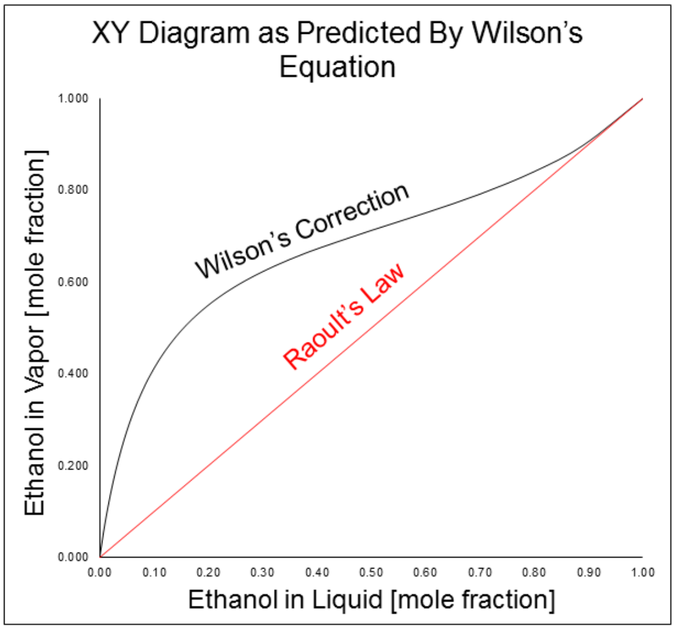
Supplemental: XY Diagrams & Wilson's Equation



Raoult's Law

$$y_a P = x_a P_a^{sat}$$

Wilson's Correction

$$y_a P = x_a \gamma_a P_a^{sat}$$

$$\gamma_a = \gamma_a(T, x_a)$$

(U//FOUO)

Supplemental: Langmuir Adsorption and the Rate Equation

$$r_{CH_3CH_2OH} \approx k[CH_3CH_2OH]$$

- **For Langmuir Adsorption:**

$$r = \frac{k K_{EtOH} P_{EtOH} K_W P_W}{[1 + K_{EtOH} P_{EtOH} + K_W P_W + K_{CH3CHO} P_{CH3CHO} + K_{AcOH} P_{AcOH}]^2}$$

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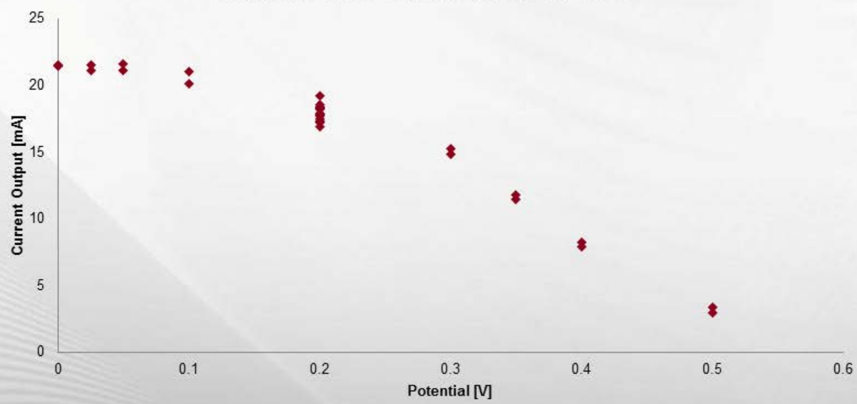
Supplemental: Variability in Fuel Cell Testing

- Fuel Cell has intrinsic variability in performance
- Operating at "standard conditions" before varying parameters reduces variability

Current vs. Potential, 250 mL/min



(U//FOUO)

Supplemental: Mass Balance Results

- Cold trap condensate compared to I-t data
- Results:
  - Yield of acetic acid was nearly quantitative with current output
  - <5% of product was CH3CHO and CO2
  - Loss of ethanol through the PEM can be bound to <10%

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Accelerated Lifetime Testing on Porous Silicon

Sauradeep Sinha, 1st summer

Junior Chemical Engineering major at UMD

Mentor: Dr. Nick Piekiel

July 27, 2015

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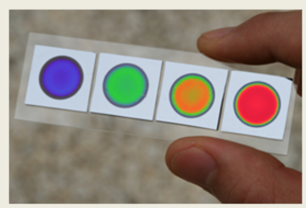
Porous Silicon

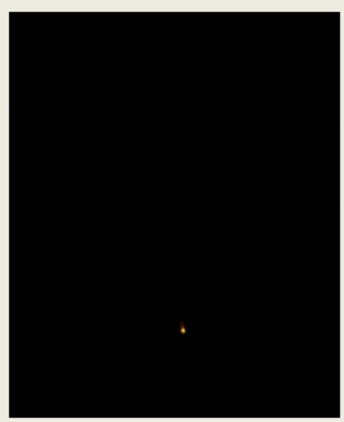
ARL

Overview:

- Porous Silicon (PS) is a high surface area (>900 m^2/g) material, formed from bulk silicon (Si)—most common substrate for MEMS and electronics.
- Typically has nanometer scale pore size
- Small pores and high surface area make it attractive for a number of applications including solar cells, biosensors, or energetic materials.



Sailor Research Group, University of California, San Diego



Porous silicon as an energetic material:

$$nSiH_2 + (1-n)Si + \frac{(2+n)}{4}NaClO_4 \rightarrow SiO_2 + NaCl + nH_2O + heat$$

- Porous silicon + oxidizer (**$NaClO_4$**, $MgNO_3$, sulfur, etc.) = high energy density system
- Highly tunable reaction rate
- Rapid combustion (3600 m/s) possible
- Low energy initiation, 10's of µJ

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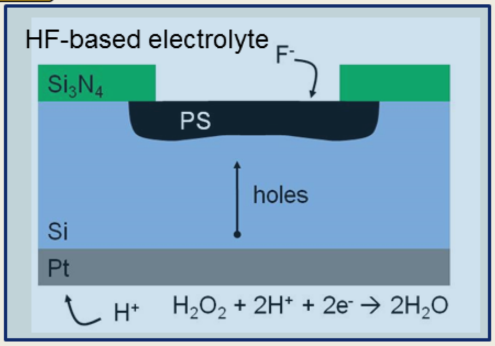
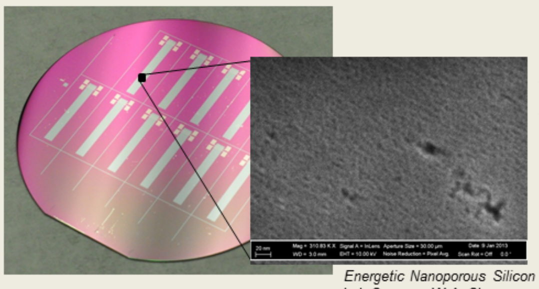
Galvanic Etch Method



Galvanic Electrochemical Etch: Ionic charge reduction at the Pt cathode, oxidation at the Si anode, current is self-generated

Si_3N_4 acts as an etch mask in HF



Energetic Nanoporous Silicon Devices, L.J. Currano, W.A. Churaman

- Easily patterned on-chip
- MEMS compatible fabrication
  - allows easy integration of PS as an on-chip energetic

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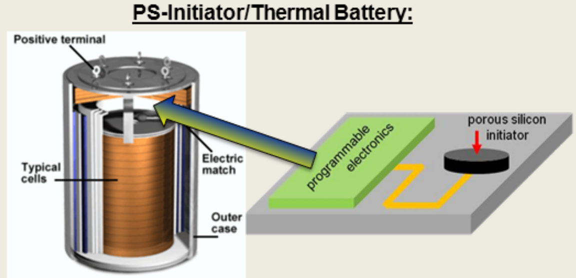
Motivation

Application:

- Fuzing and initiation
  - Initiator for thermal batteries (ManTech Project, in collaboration with ARDEC)
  - MEMS Safe and Arm Initiator (collaboration with ARDEC)

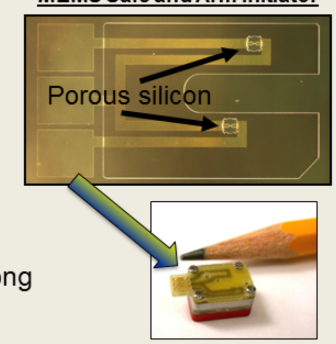
PS-Initiator/Thermal Battery:



Problem:

- These applications require long lifetimes–up to 20 years
- Little work on understanding aging and the total lifetime of PS
  - In the news: Pyrotechnic inflator system failures in air bags

MEMS Safe and Arm Initiator



Focus: Determine lifetime and gain better insight into the long term chemical nature of PS

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Sample Fabrication

ARL

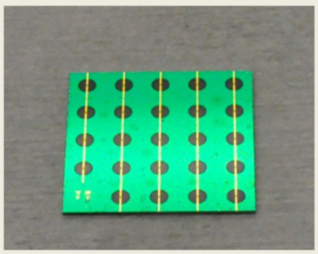
Start with basic silicon wafer with a protective nitride layer and platinum (cathode for etch).

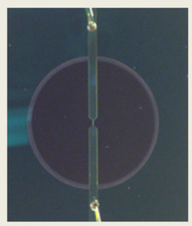
Selectively etch nitride (DRIE) to pattern in a design and apply gold bridgewires through sputter deposition.

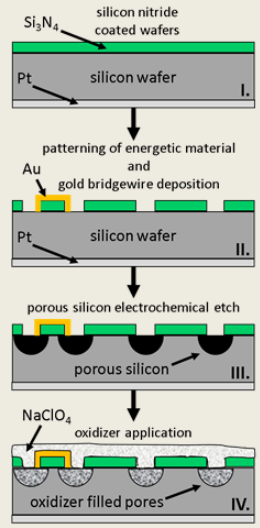
Place in hydrofluoric acid solution for porous silicon etch.

Singulate 2 mm PS regions and electrically connect them to a dual in-line package.

Oxidizer was added to the pores and dried.







Approximately 300 devices have been tested.

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Experimental Methods

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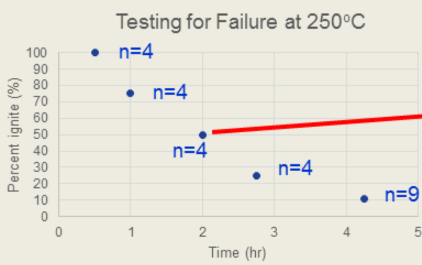
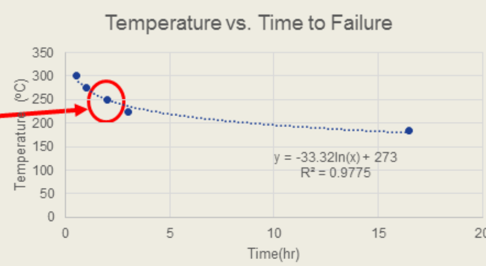
Accelerated aging tests

Samples are aged by baking at a specified elevated temperature and electrically ignited at low voltage for set intervals of time until failure point is reached.

- Needs to last 20 years
- Accelerated lifetime tests
  - High temperature, heat to failure, mimics long term conditions





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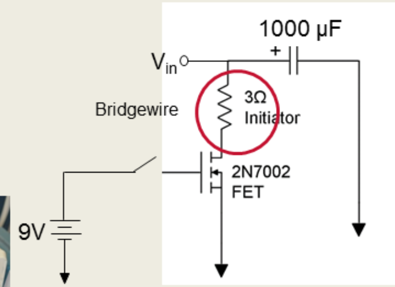
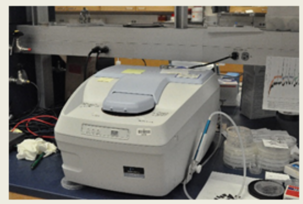
Experimental Methods

- Electrical testing: Recorded current and voltage through the bridgewire during ignition
    - Measure power, energy and time to burst when devices are electrically ignited.

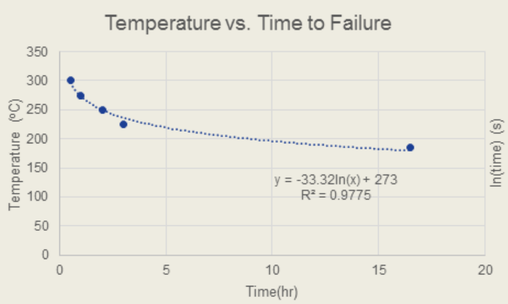


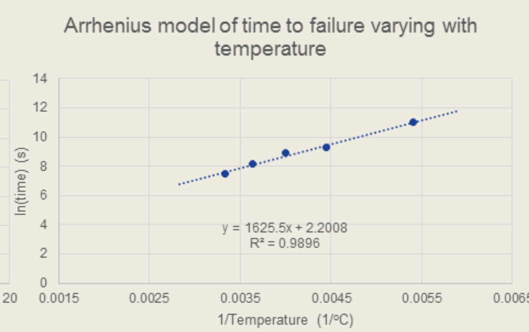
- Differential Scanning Calorimetry (DSC):
    - Analyze endothermic and exothermic events of PS along a temperature profile.



Failure Times

Determination of failure times, which are the time points when at least 50% of the packaged devices do not ignite at a given temperature





Arrhenius Equation from NIST Handbook:
$\ln(t_f)=(\Delta H/kT)+\ln(A)$

Number of devices tested: At least 20 devices were tested per experiment at a specified temperature
Estimated lifetime at 20 °C using Arrhenius model: **23 years**

What is causing failure?

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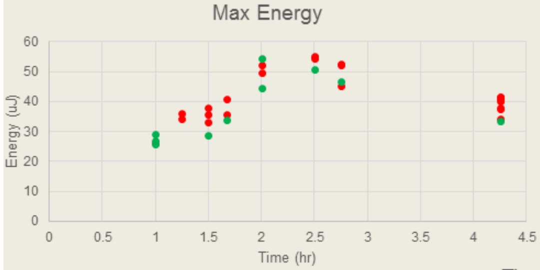
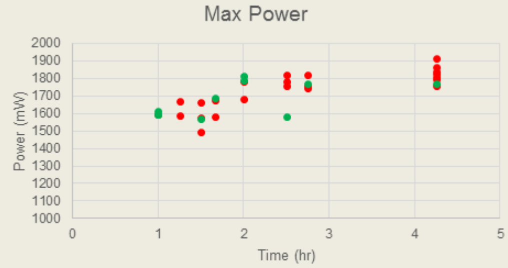
Electrical Data at 250°C

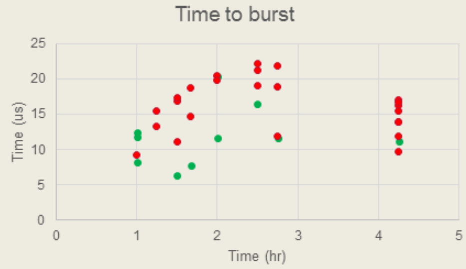
ARL

Concerned with bridgewire failing due to aging





Electrical Data through bridgewire of devices during ignition



Green – ignited
Red – failed to ignite

Takeaway: These graphs show that the bridgewire and electrical connections are not failing during aging.

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Qualitative Analysis

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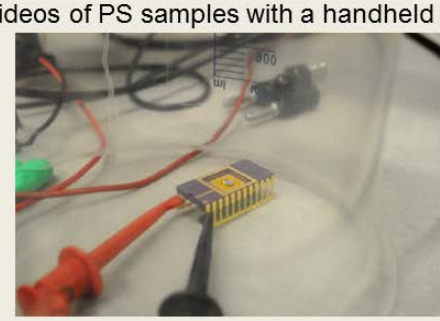
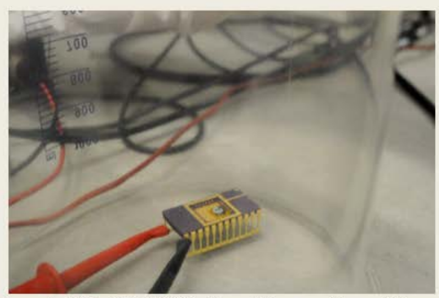
Electrical ignition not causing failure

- Failure must be due to chemical reaction between porous silicon/$NaClO_4$
- Qualitatively observe reduced performance during aging

Videos of PS samples with a handheld DSLR



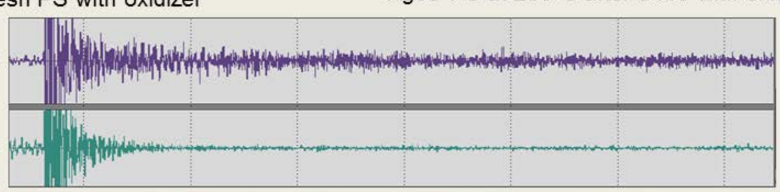
Fresh PS with oxidizer



Aged PS at 200°C after 5 hrs with oxidizer

Fresh sample

Aged sample



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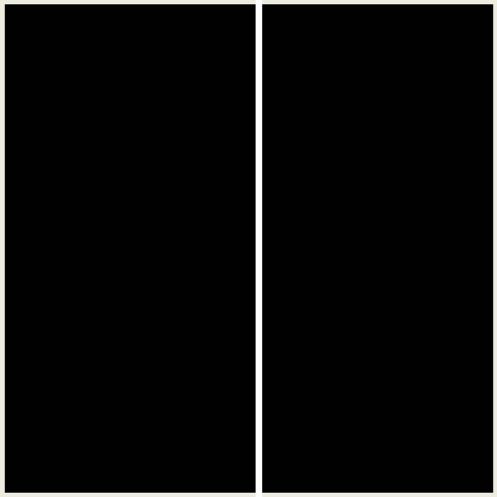
Qualitative Analysis

Visual comparison of PS samples with High Speed Camera at 60,000 frames/sec

Fresh sample burns twice as fast as the aged sample



Nearing point of failure

Fresh PS with oxidizer

Aged PS at 200 ^{o}C after 5 hrs with oxidizer

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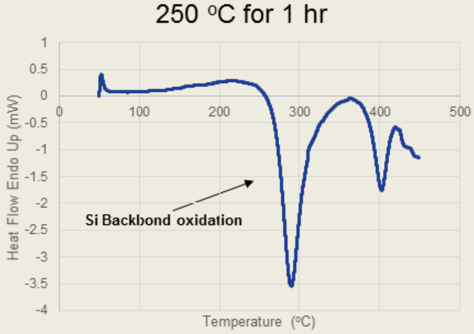
Differential Scanning Calorimetry

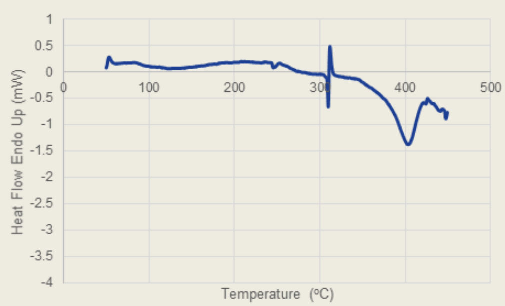
- DSC of two samples near the failure point
- Change in DSC traces show chemical reaction occurs during aging

Failure point at 250 ^{o}C is 2 hrs

250 ^{o}C for 1 hr



250 ^{o}C for 1.67 hrs



- Observing system failure due to reaction between PS/$NaClO_4$

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Differential Scanning Calorimetry

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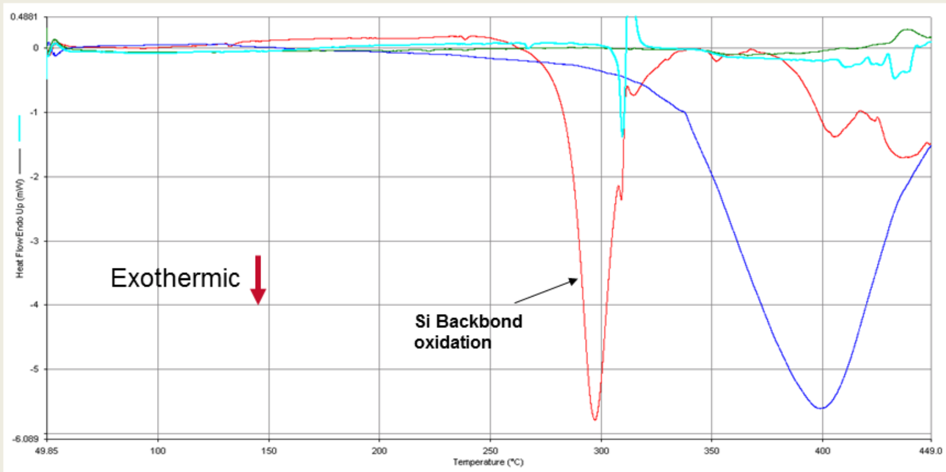
Heat Flow vs. Temperature baseline samples: Fresh oxidized PS, Not oxidized PS, unetched Silicon and $NaClO_4$



Red – fresh oxidized PS

Blue – Not oxidized PS

Light Blue – $NaClO_4$

Green - Unetched Silicon

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Si Backbond Oxidation

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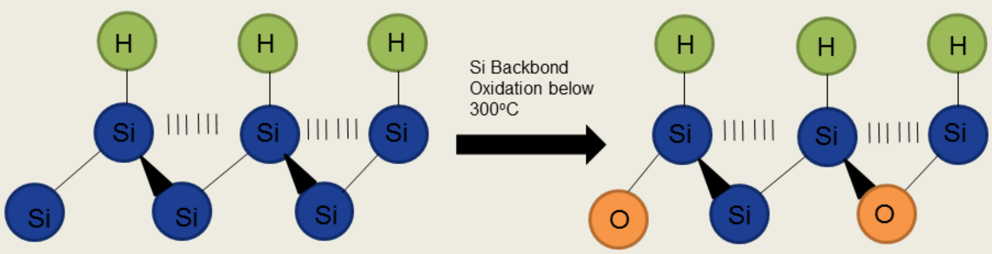
- Collin Becker's paper *Thermal Analysis of the Exothermic Reaction between Galvanic Porous Silicon and Sodium Perchlorate* notes Si backbond oxidation occurs below 300 °C.
- Backbond oxidation is believed to be a crucial step for ignition.



- When this oxidation occurs during aging, it consumes silicon fuel, thus reducing performance during ignition (or can prevent ignition).

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Conclusions

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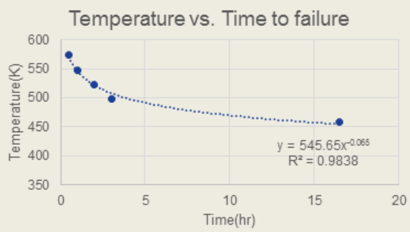
- Investigated lifetime of PS through accelerated aging tests in support of mission critical Army programs
- Obtained an estimated lifetime of PS at ambient conditions ~ 23 years
- Demonstrated aging affects chemical nature of PS
  - Electrical data showed no effect on electrical connections
  - DSC showed evidence of impacting Si backbond oxidation
- **Study shows importance of Si backbond oxidation in ignition and knowledge can be used in processing and storing PS+oxidizer systems**
  - When integrating with other MEMS devices or fabrication techniques, we now have temperatures guidelines for processing



- Future studies:
  - Obtain more failure times at varying temperatures
  - Humidity chamber experiments on packaged devices

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Electrical and Optical Characterization of CVT Grown $Mo_xW_{1-x}Te_2$ Alloys

Daniel Rhodes
[1]Florida State University/NHMFL

Daniel Chenet[2], Tyler Klarr[3,4], Alexander Duerloo[5], Alex Mazzoni[3,6], Sina Najmaei[3], Qiu Run Zhang[1], Robert Burke[3]

Mentor: Matthew Chin[3]
Team Leader: Madan Dubey[3]
PHD Advisor: Dr. Luis Balicas[1]
[2]Columbia University, [3]ARL, [4]Oregon State University, [5]Standford University, [6]University of Maryland

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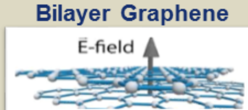
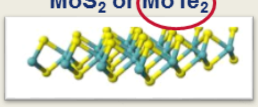
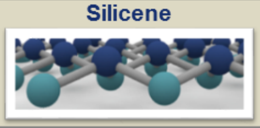
Properties of 2D Materials

Material	Bandgap	Properties
Graphene 	E_g = 0 eV	• Ambipolar conduction • Best thermal conductivity (in-plane) • Record e^-/h^+ mobility
Bilayer Graphene 	E_g = f(E)	• Direct bandgap controlled by E-field • Potential for exciton condensate
MoS_2 or $MoTe_2$ 	$E_{g\text{-mono}}$ (MoS_2) = 1.8 eV direct $E_{g\text{-mono}}$ ($MoTe_2$) = 1.1 eV direct	• Excellent semiconductor • Phase transition (1T Metallic to 2H Semico.) • Can be used in optoelectronics
Silicene 	E_g = 0.1-0.5 eV indirect	• Bandgap is tunable based on doping • Semiconductor industry compatible • Stability issues
Phosphorene 	E_g = 0.3-1 eV direct	• Bandgap is tunable based on thickness • Mobility predicted to be 10,000 $cm^2/V\cdot s$ • Stability issues

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TMDC Introduction

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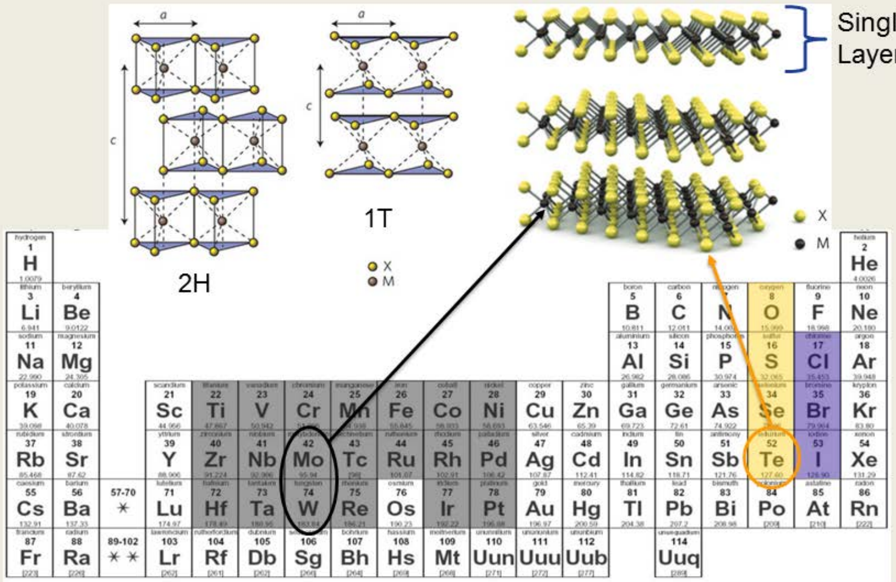

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TMDC Phase Transition

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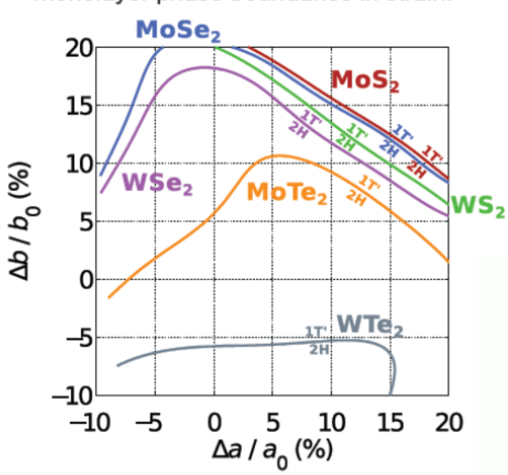
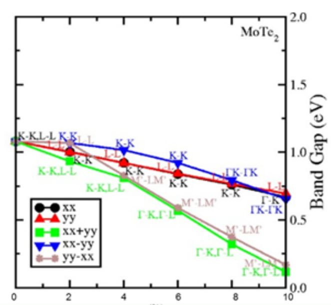
Our DFT/PBE calculations of TMD monolayer phase boundaries in strain.



Duerloo, Li, Reed, Nature Communications, (2014).



Published in: Priya Johari; Vivek B. Shenoy; *ACS Nano* **2012,** 6, 5449-5456. DOI: 10.1021/nn301320r

Published in: Karel-Alexander N. Duerloo; Yao Li; Evan J. Reed; *Nature Comm* **2014** 5, 4214 DOI: 10.1038/ncomms5214

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Project Outline

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Project Goals:

- Modulate the bandgap of $MoTe_2$ by alloying with WTe_2.
- Adjust stoichiometry to tune metal-to-semiconductor phase transition temperature.
- Develop unique device fabrication techniques.

Background Motivation and Relevance for ARL/Army:

- Could offer a route to sensitive 2D infrared detectors.
- Possible applications in 2D thermally sensitive devices.
- Non-volatile memory.
- Strain modulated transistors.

Technical Challenges:

- Producing selective stoichiometry.
- Analyzing and understanding the photon-phonon interactions via Raman.
- Observing the bandgap and gradual transition into metallic phase.
- Creating electrical devices to apply thermal energy or strain.

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Experimental Results

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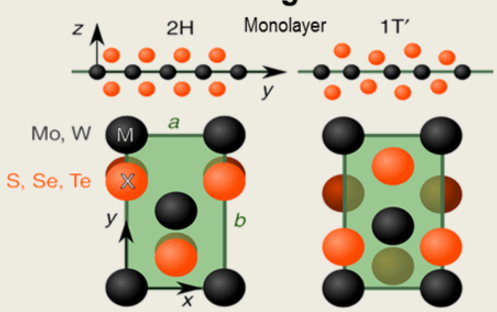
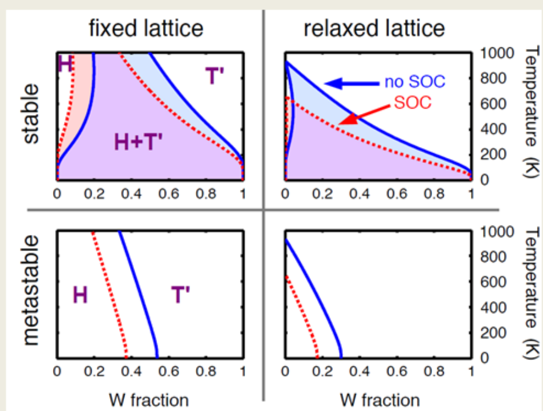
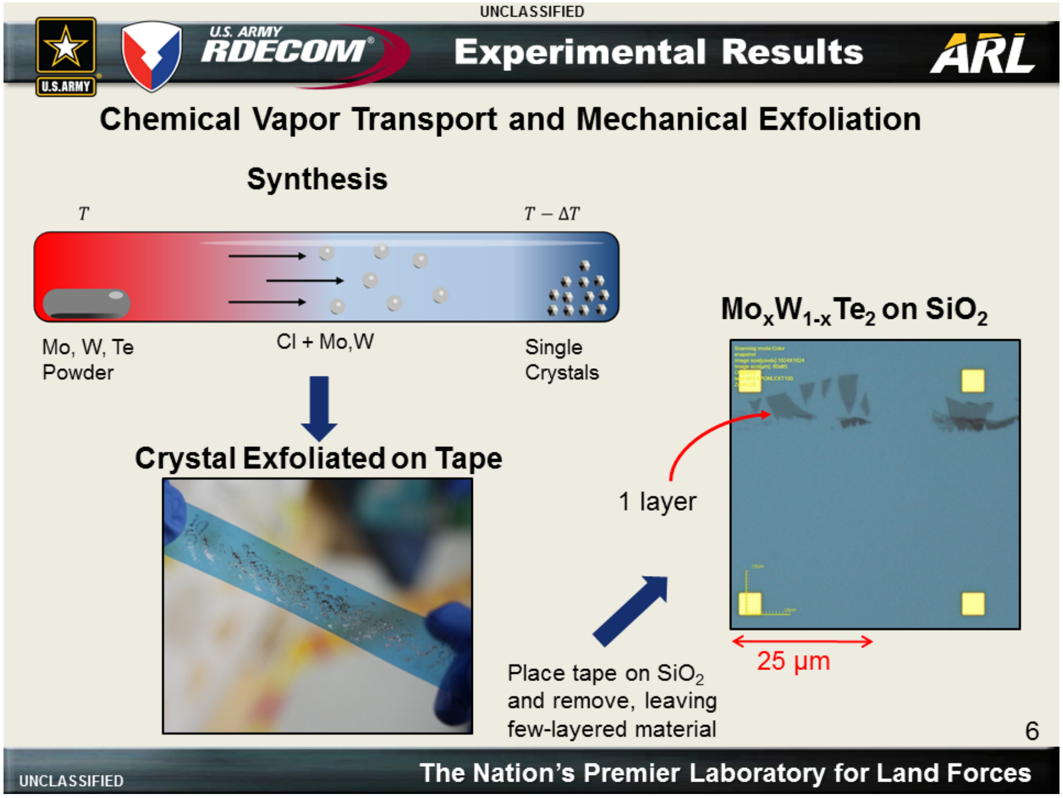
Semiconducting Metallic

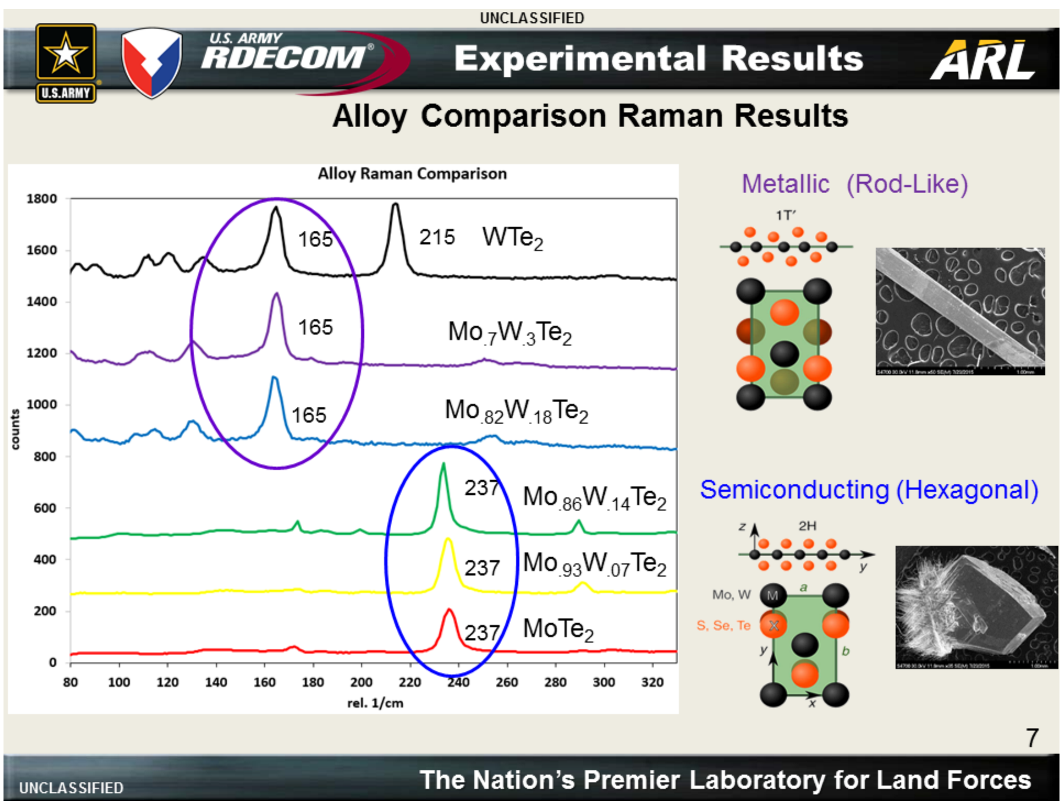


Theoretical Phase Diagram

Spin Orbit Coupling
No Spin Orbit Coupling







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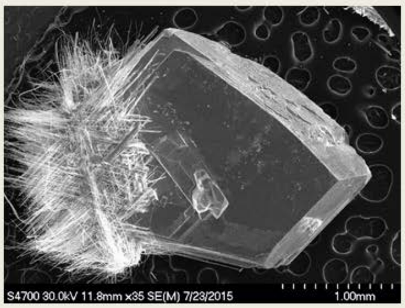
Experimental Results

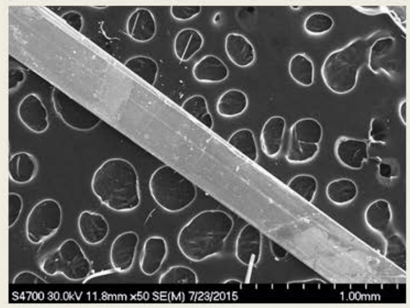
EDX Results

Phase	Mo Atomic %	W Atomic %	Te Atomic %	W:Mo Ratio	Overall Stoichiometry
1T'	23.5	11.0	65.4	**.47**	$Mo_{.68}W_{.32}Te_{1.9}$
1T'	23.6	9.6	66.8	**.41**	$Mo_{.71}W_{.29}Te_{2}$
2H	28.7	4.6	66.8	**.16**	$Mo_{.86}W_{.14}Te_{2}$
2H	29.8	2.8	67.5	**.09**	$Mo_{.92}W_{.08}Te_{2.1}$

2H crystal with 1T growing from the edge



Single 1T bulk crystal



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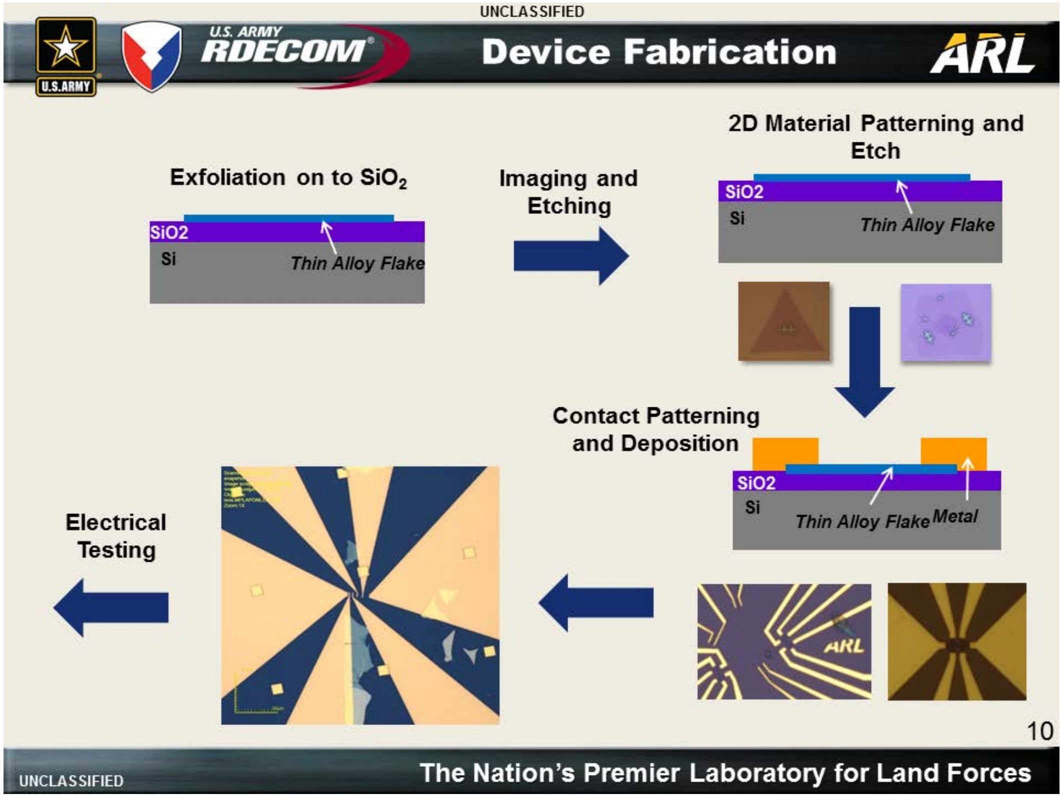
Experimental Results

Phase transition via laser exposure

9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Device Fabrication
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Exfoliation on to SiO_2
SiO2
Si
Thin Alloy Flake
Imaging and Etching
2D Material Patterning and Etch
SiO2
Si
Thin Alloy Flake
Contact Patterning and Deposition
SiO2
Si
Thin Alloy Flake
Metal
Electrical Testing
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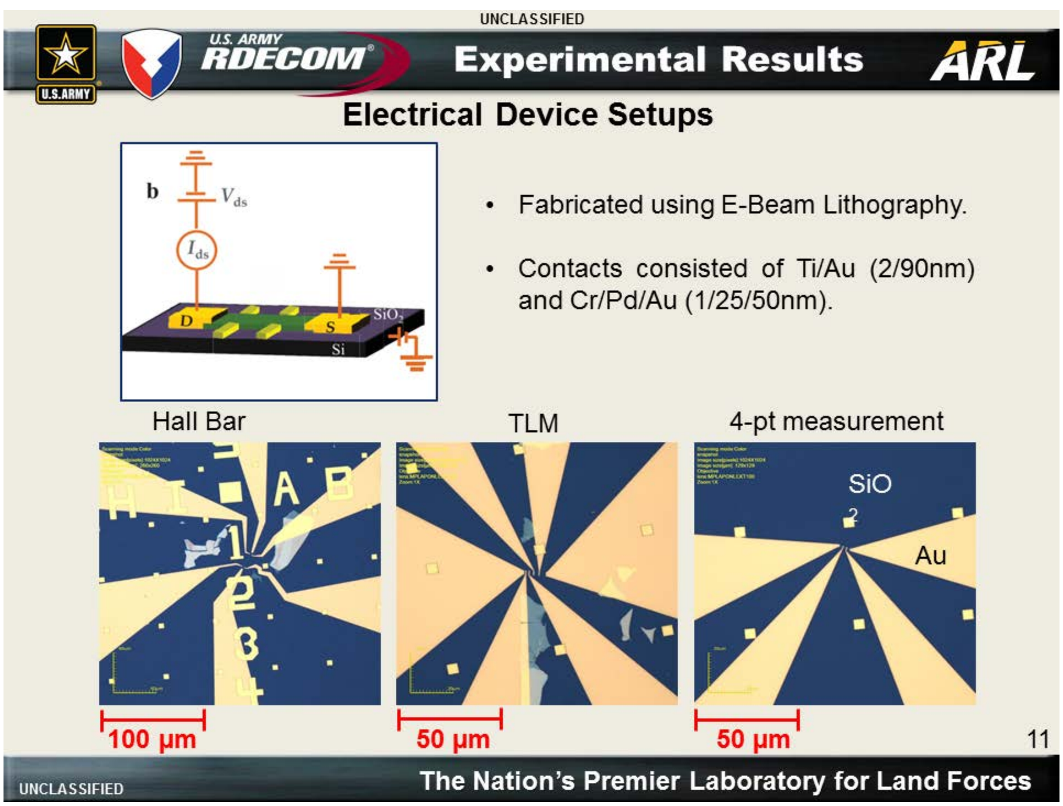
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Experimental Results
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Electrical Device Setups
b
V_{ds}
I_{ds}
D
S
SiO_2
Si
• Fabricated using E-Beam Lithography.
• Contacts consisted of Ti/Au (2/90nm) and Cr/Pd/Au (1/25/50nm).
Hall Bar
TLM
4-pt measurement
SiO
2
Au
100 μm
50 μm
50 μm
11
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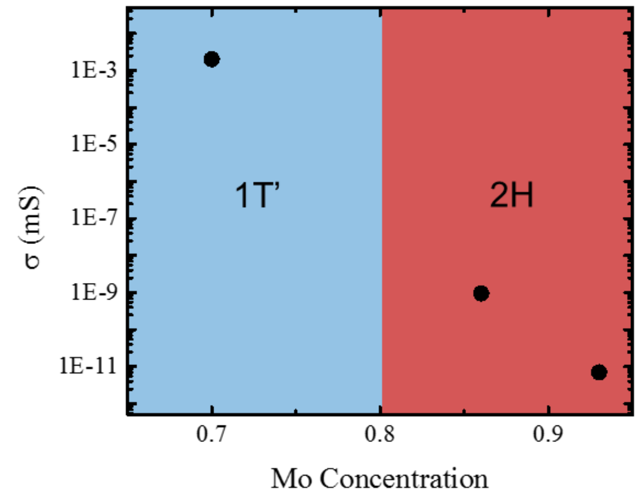
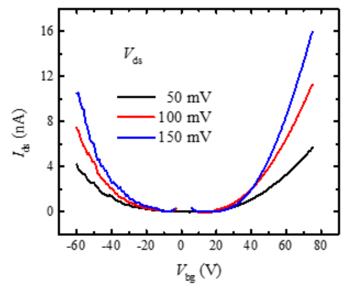
Experimental Results

Electrical Conductivity for 2H and 1T



2H turning on/off



Summary

- We have synthesized a variety of alloys for the $Mo_xW_{1-x}Te_2$ system, resulting in both the 2H and 1T' phase (prepared at FSU in preparation for ARL internship).
- An initial study of the stoichiometry has been carried out.
- The alloys have been examined using Raman spectroscopy. We have found various peaks, which are associated with the 1T' and 2H phases for MoTe2.
- We have observed a phase transition via laser heating.
- Devices were fabricated for characterizing electrical properties of the alloys.
- The alloys have been examined electrically, and show semiconducting behavior for low concentrations of W to Mo and semi-metallic for higher concentrations.

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Future Work

- Temperature dependence of current 2D materials using a graphene heater.
- More materials characterization (TEM, TOF-SIMS, XPS, XRD, and EDX).
- Further synthesis and tuning of the phase transition from growth.
- Temperature and polarization-dependent Raman analysis.
- Contact optimization for more reliable electrical measurements and more electrical measurements.
- Refining laser patterning of 1T' phase.
- Strain-device engineering or thermal device engineering to induce phase transition from 2H to 1T'.

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Acknowledgments

I would like to thank ARL for the opportunity to conduct interesting and meaningful research as an intern.

I would also like to acknowledge ARO and the NSF for facilities and support before arriving at ARL.

Thanks to those who helped me with this project:

Daniel Chenet*	Sina Najmaei
Tyler Klarr*	Madan Dubey (Team Leader)
Alex Mazzoni	Luis Balicas (PHD Advisor)
Matthew Chin (Mentor)	
Matthew Hwee	
Robert Burke	

(*contributed towards Raman, composition characeterization, and planning project)

And a particular thanks to Alexander Duerloo and Evan Reed for providing theoretical calculations.

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Thank you for your time.

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Experimental Results

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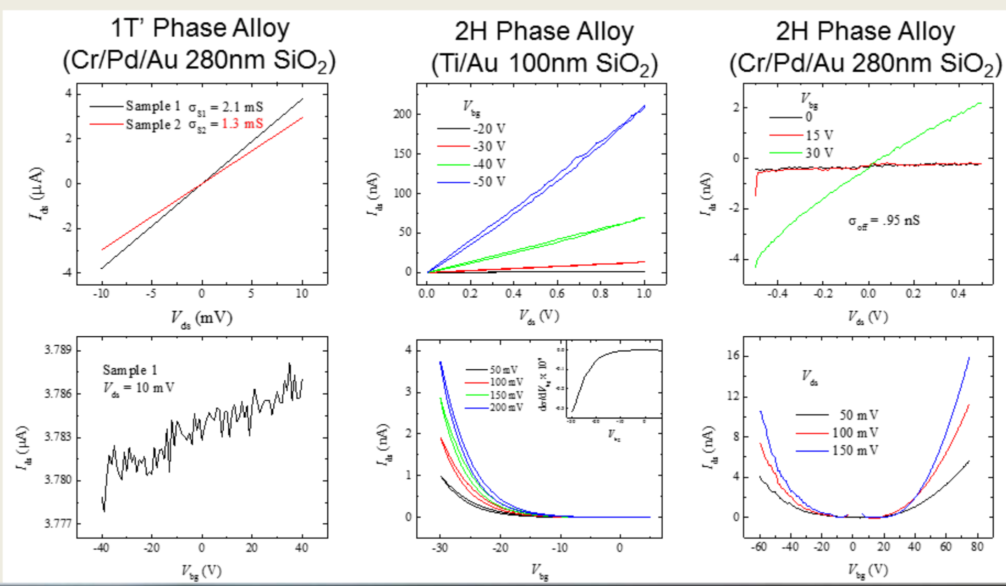
Electrical Conductivity for 2H and 1T



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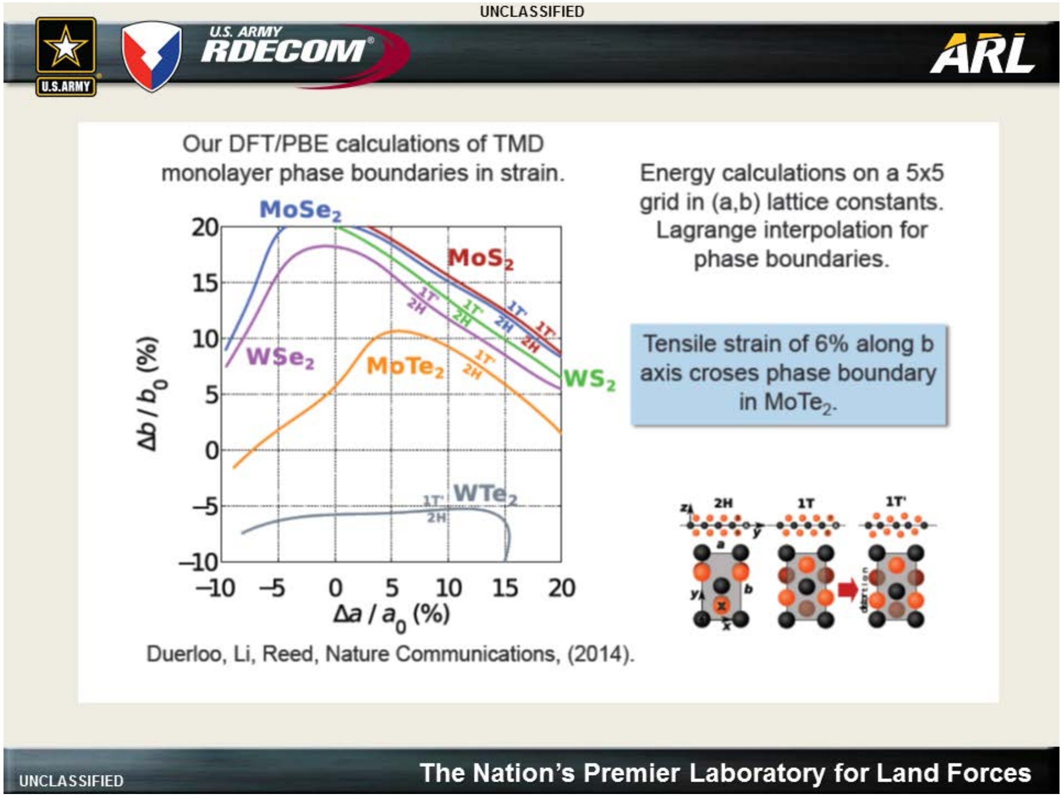
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Our DFT/PBE calculations of TMD monolayer phase boundaries in strain.
MoSe$_2$
MoS$_2$
WSe$_2$
MoTe$_2$
WS$_2$
WTe$_2$
1T'
2H
$\Delta b / b_0$ (%)
$\Delta a / a_0$ (%)
Duerloo, Li, Reed, Nature Communications, (2014).
Energy calculations on a 5x5 grid in (a,b) lattice constants. Lagrange interpolation for phase boundaries.
Tensile strain of 6% along b axis croses phase boundary in MoTe$_2$.
2H
1T
1T'
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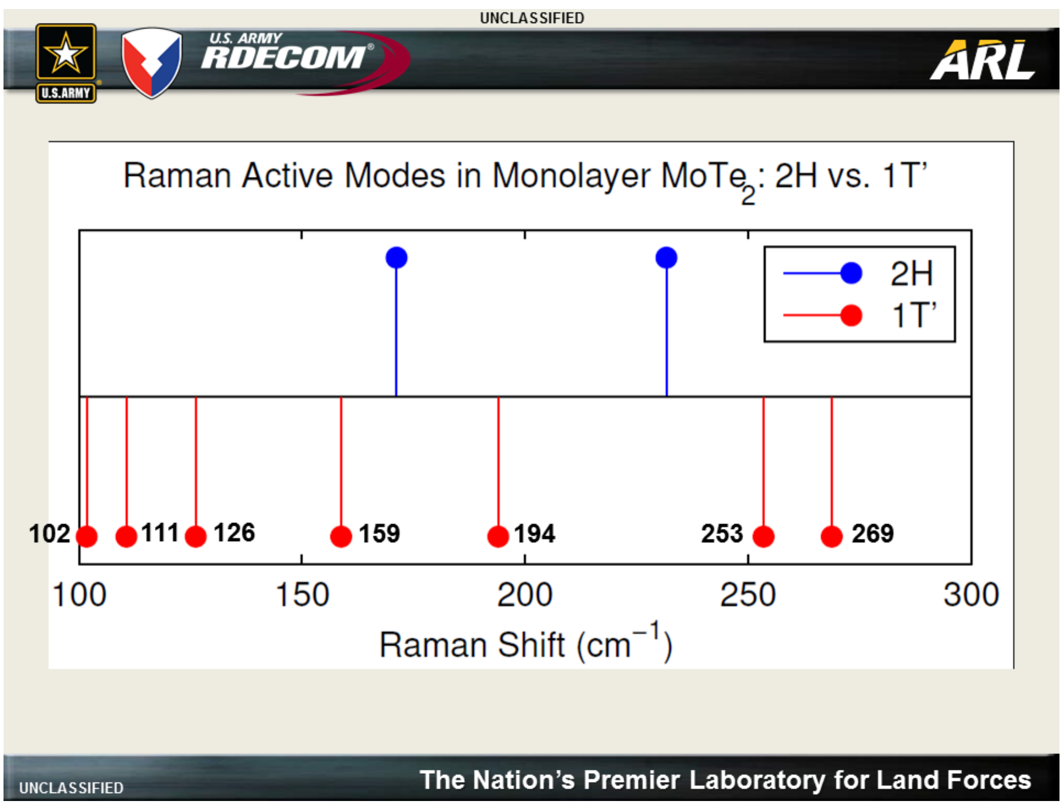
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Raman Active Modes in Monolayer MoTe$_2$: 2H vs. 1T'
2H
1T'
102
111
126
159
194
253
269
100
150
200
250
300
Raman Shift (cm^{-1})
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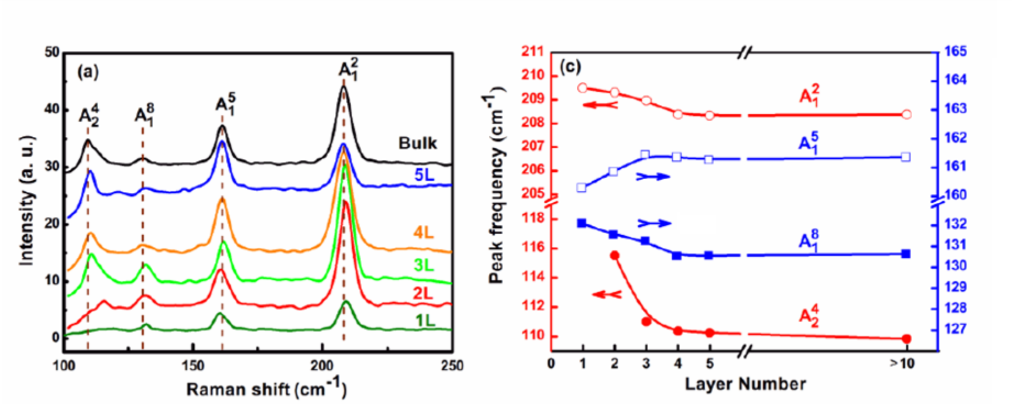
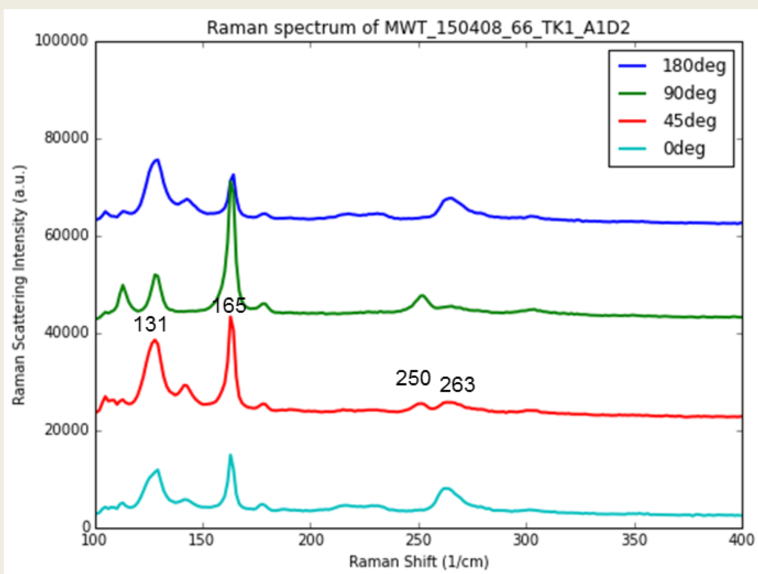
WTe_2 Raman Peaks and Layer Dependence

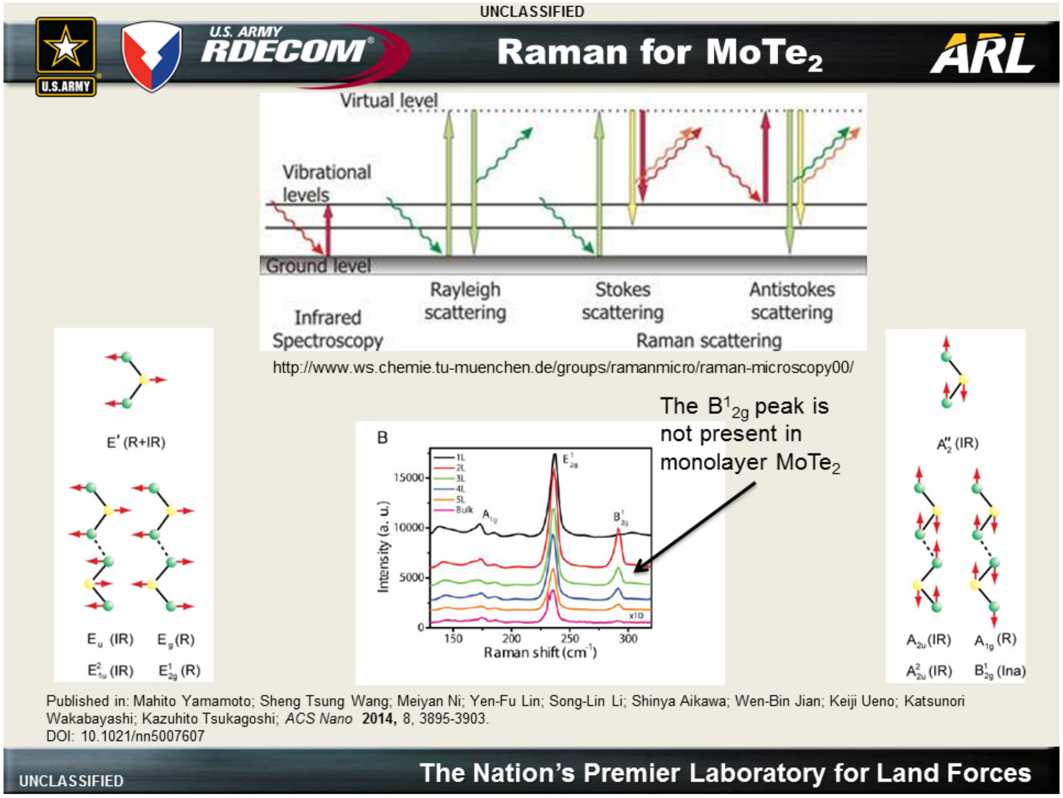


Yucheng Jiang, Ju Gao, arXiv:1501.04898 (2015)

Experimental Results

Polarization Dependent Raman Results

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Raman for MoTe2
ARL
Virtual level
Vibrational levels
Ground level
Infrared Spectroscopy
Rayleigh scattering
Stokes scattering
Antistokes scattering
Raman scattering
http://www.ws.chemie.tu-muenchen.de/groups/ramanmicro/raman-microscopy00/
E′ (R+IR)
E_u (IR) E_g (R)
E²_1u (IR) E¹_2g (R)
The B¹2g peak is not present in monolayer MoTe2
Intensity (a. u.)
Raman shift (cm⁻¹)
1L
2L
3L
4L
5L
Bulk
A″2 (IR)
A2u (IR) A1g (R)
A²2u (IR) B¹2g (Ina)
Published in: Mahito Yamamoto; Sheng Tsung Wang; Meiyan Ni; Yen-Fu Lin; Song-Lin Li; Shinya Aikawa; Wen-Bin Jian; Keiji Ueno; Katsunori Wakabayashi; Kazuhito Tsukagoshi; ACS Nano 2014, 8, 3895-3903.
DOI: 10.1021/nn5007607
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Vehicle Technology Directorate (VTD)

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Active Flap Rotor Modeling for Aeromechanics Predictions

Ethan Corle
Department of Aerospace Engineering
The Pennsylvania State University

Outline

- Motivation
- Background
- Methodology
  - RCAS Model
- Results
  - Fan Plots
  - Load Comparisons

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Motivation

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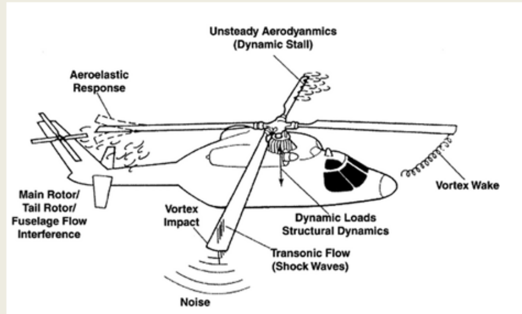
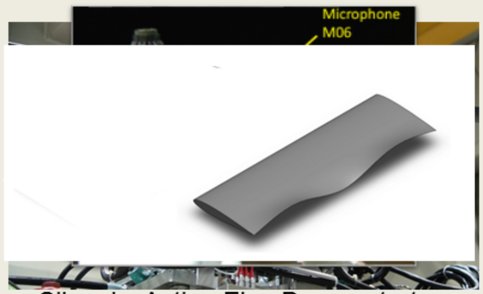
Compromised design of rotor blades

- Differing aerodynamic conditions across flight envelope.

Active rotor technologies

- Dynamically change airfoil characteristics to alter blade loading
  - Both aerodynamic and structural effects
  - Used to increase performance, reduce vibrations, and reduce noise





Blade Morphing (University of Michigan)
Sikorsky Active Flap Demonstrator

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SMART Rotor

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Smart Material Advance Rotor Technologies (SMART) Rotor Program

- DARPA Helicopter Quieting Program
- Army, NASA, Boeing
- Designed to improve and validate the current state-of-the-art in active rotor modeling
- Accurate models can provide reliable predictions prior to expensive testing

End Goal: Investigate active flap aeromechanics and utilize understanding to make optimized flap deployment schedules

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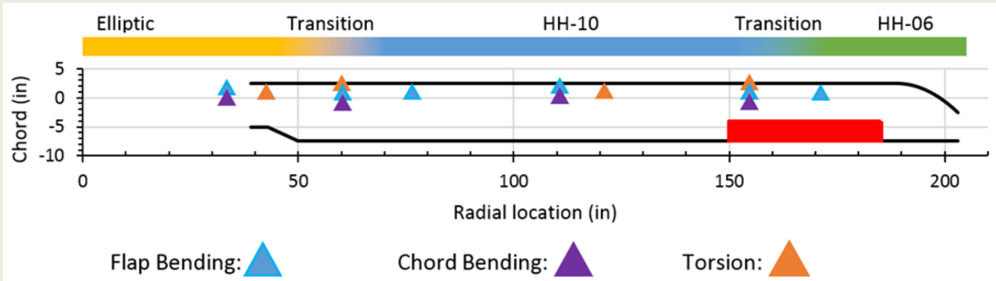
Background

SMART Rotor Test Campaign



Planned Deployments

Table 1. Planned SMART Rotor Test Cases

Name	C_T/σ	μ	Deployment Schedule
MDART	0.080	0.3	$\delta_n = 0°$
SMART1	0.080	0.3	$\delta_n = 2° \cdot \sin(5 \cdot \psi_n + 90°)$
SMART2	0.080	0.3	$\delta_n = 2° \cdot \sin(3 \cdot \psi_n + 60°)$
SMART3	0.070	0.375	$\delta_n = 1° \cdot \sin(5 \cdot \psi_n + 180°)$
SMART4	0.075	0.3	$\delta_n = 2° \cdot \sin(2 \cdot \psi_n + 240°) + 1° \cdot \sin(5 \cdot \psi_n + 330°)$

Where n is the blade index

(Straub et al. – 2009, Lau et al. – 2010)

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Previous Work

Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) II Modeling (Kottapalli – 2010,2011)

- **Predictions:**
  - Flap hinge stiffness sensitivity
  - Alterations to airfoil tables

Coupled fluid-structure modeling (Potsdam et al. – 2010)

- OVERFLOW 2.0aa and CAMRAD II
- Challenging multidisciplinary problem
- Little improvement over comprehensive analysis

Current state of the art

- Large discrepancies between analysis and test data
- Aeromechanics of active flap not fully understood

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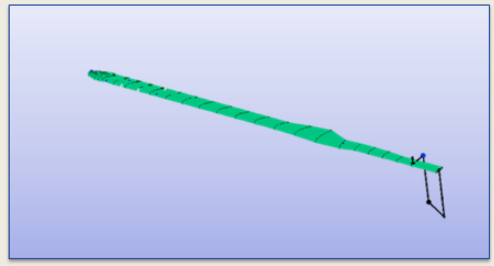
U.S. ARMY RDECOM® **Computational Tools** ARL

The Rotorcraft Comprehensive Analysis System (RCAS)

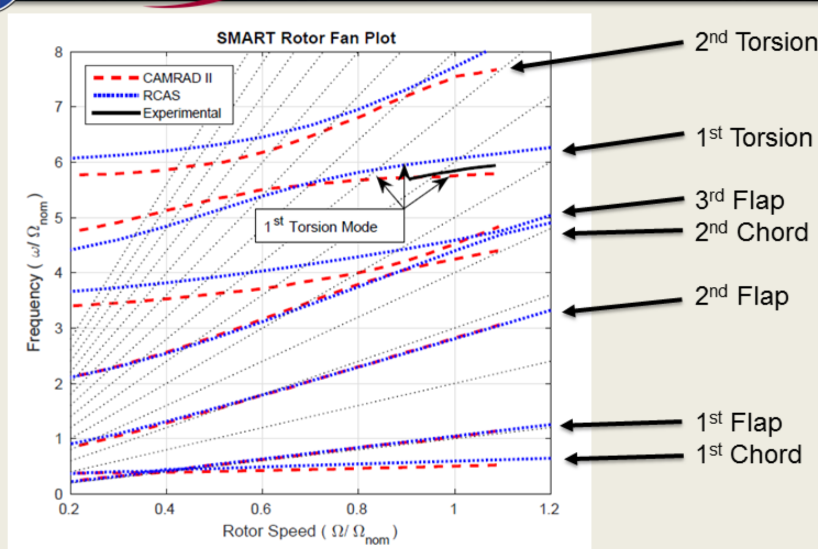
- Army-owned multidisciplinary, flexible multibody for rotorcraft aeromechanic analysis

RCAS Structural Model

- Geometrically exact
  - Control system
  - Blade root connections
  - Flap connections
- Nonlinear beam elements
  - Sectional material properties
  - Separate elements for blade and flap segments



U.S. ARMY RDECOM® **Structural Natural Frequencies** ARL



Structural model is in good agreement with previous studies

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Computational Tools

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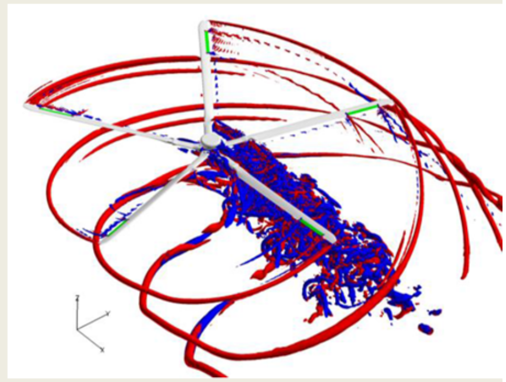
RCAS Aerodynamic Model

- Nonlinear, unsteady
- Computationally efficient
- Empirical model for blade/flap effects
- Trimmed to fixed C_T/σ and measure pitch and roll moments



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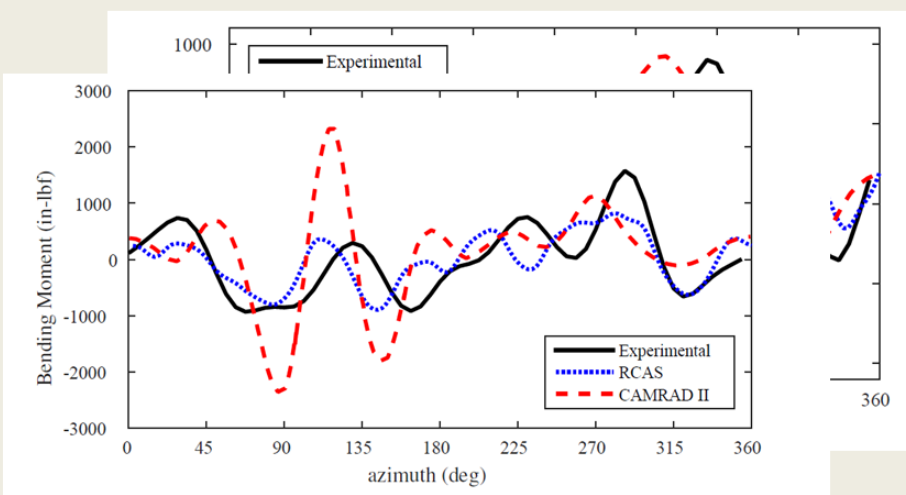
Results

ARL

SMART1: Flap Bending Moment 89% Span

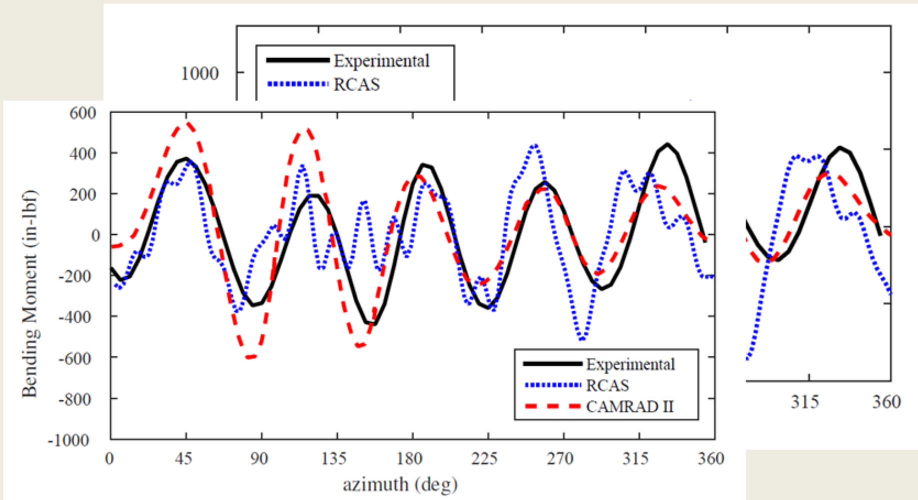
$$V = 208\frac{ft}{s}, \quad \delta_{flap} = 2^o \sin(5\psi_n + 90^o)$$



U.S. ARMY RDECOM — **Results** — ARL

SMART1: Torsion 64% Span

$$V = 208\frac{ft}{s}, \quad \delta_{flap} = 2^o \sin(5\psi_n + 90^o)$$



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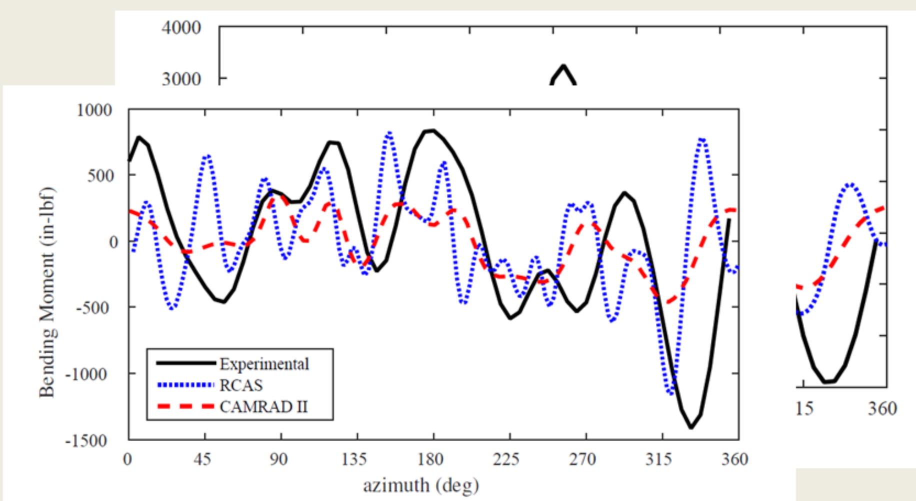
U.S. ARMY RDECOM — **Results** — ARL

SMART1: Chord Bending Moment 89% Span

$$V = 208\frac{ft}{s}, \quad \delta_{flap} = 2^o \sin(5\psi_n + 90^o)$$



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Conclusion & Looking Forward

ARL

Conclusion

- First RCAS SMART rotor model developed and validated
  - Good correlation with structural model
  - Fair correlation with experimental loading data
- Higher harmonic content observed in chordwise bending and torsional loads
  - Blade flap interference model not adequate to complex aerodynamic interactions

What's Next?

- Finish baseline cases for other SMART deployments
- Investigate alternative flap modeling
- Implement Helios for CFD/CSD predictions

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Acknowledgements

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Mentors:

- Rajneesh Singh
- Hao Kang
- Matthew Floros
- Sven Schmitz

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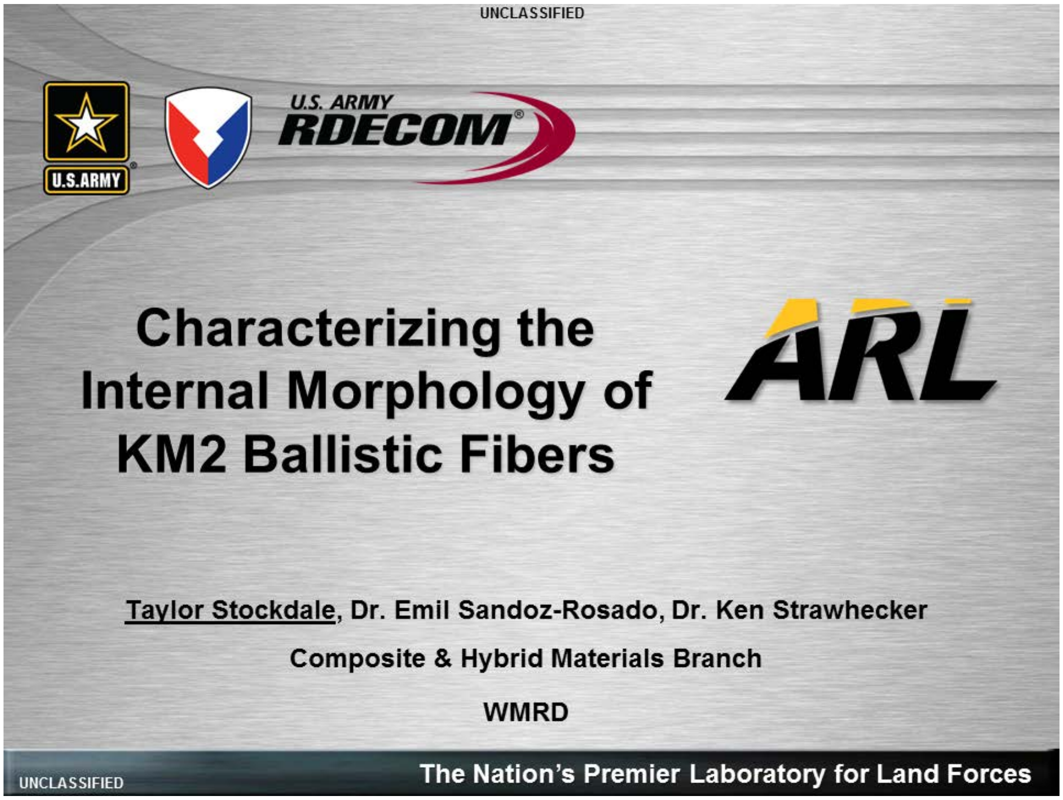

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Characterizing the Internal Morphology of KM2 Ballistic Fibers
ARL
Taylor Stockdale, Dr. Emil Sandoz-Rosado, Dr. Ken Strawhecker
Composite & Hybrid Materials Branch
WMRD
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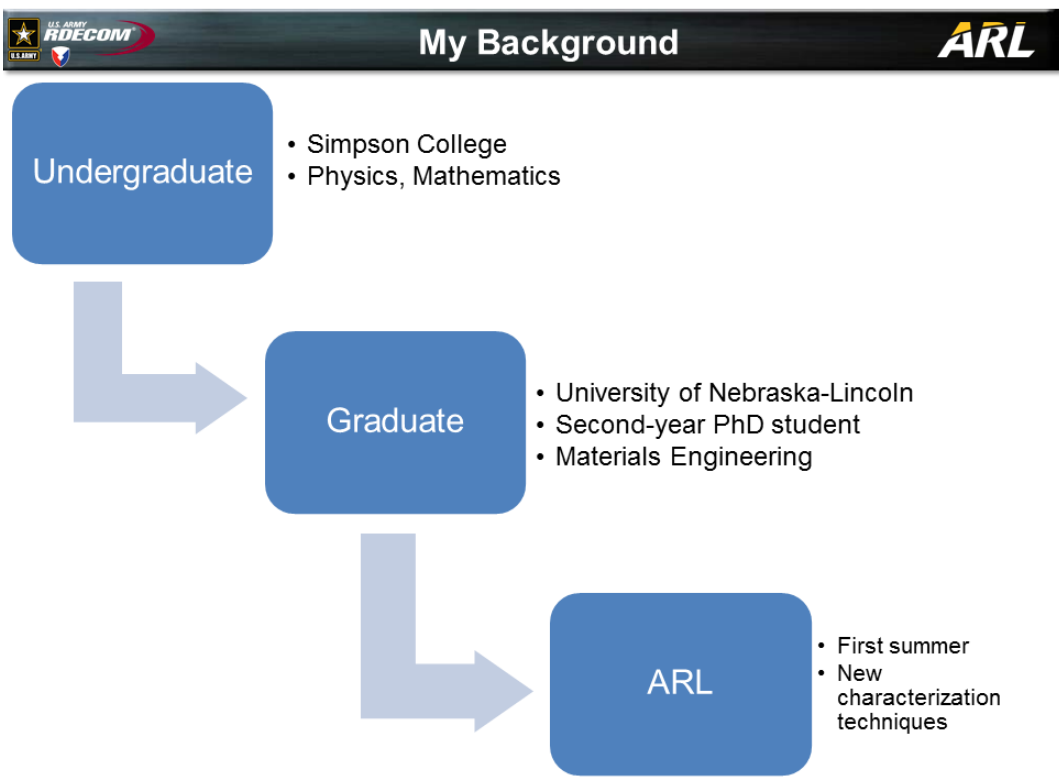
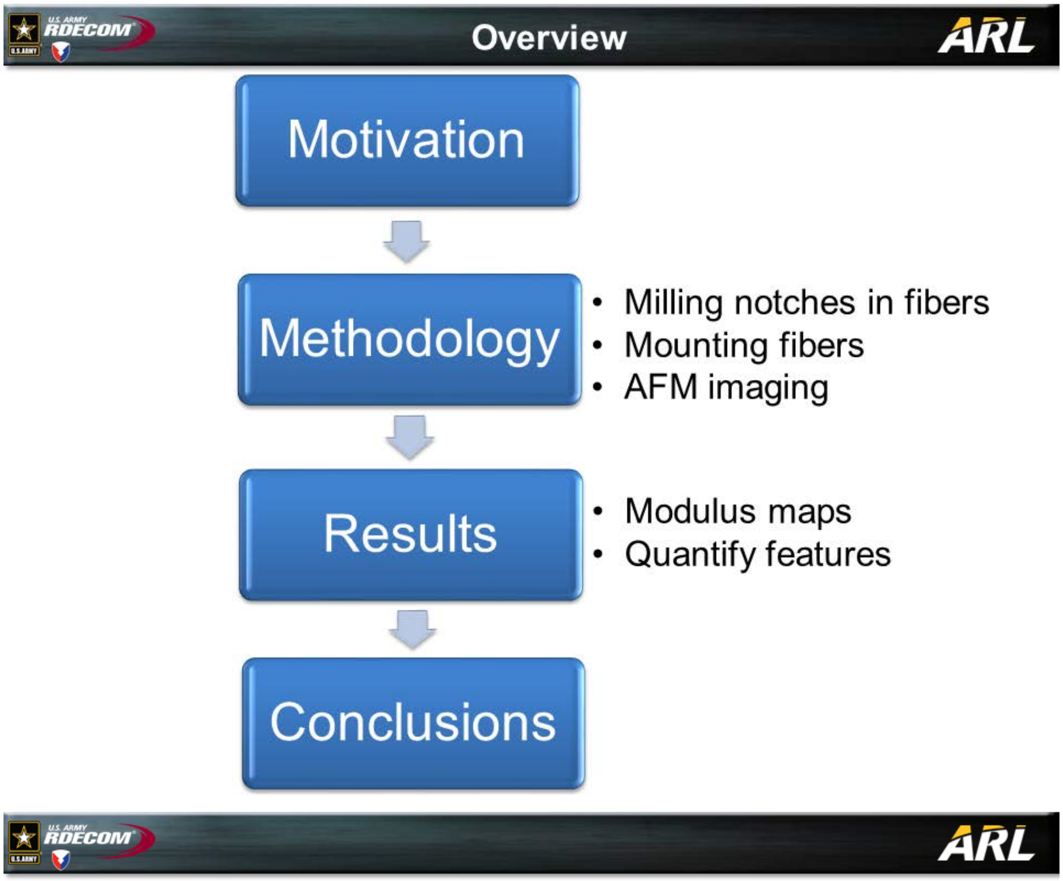


My Background
ARL
Undergraduate
• Simpson College
• Physics, Mathematics
Graduate
• University of Nebraska-Lincoln
• Second-year PhD student
• Materials Engineering
ARL
• First summer
• New characterization techniques


U.S. ARMY RDECOM
Overview
ARL
Motivation
Methodology
• Milling notches in fibers
• Mounting fibers
• AFM imaging
Results
• Modulus maps
• Quantify features
Conclusions
U.S. ARMY RDECOM
ARL

Motivation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Mission: Protecting Our Soldiers
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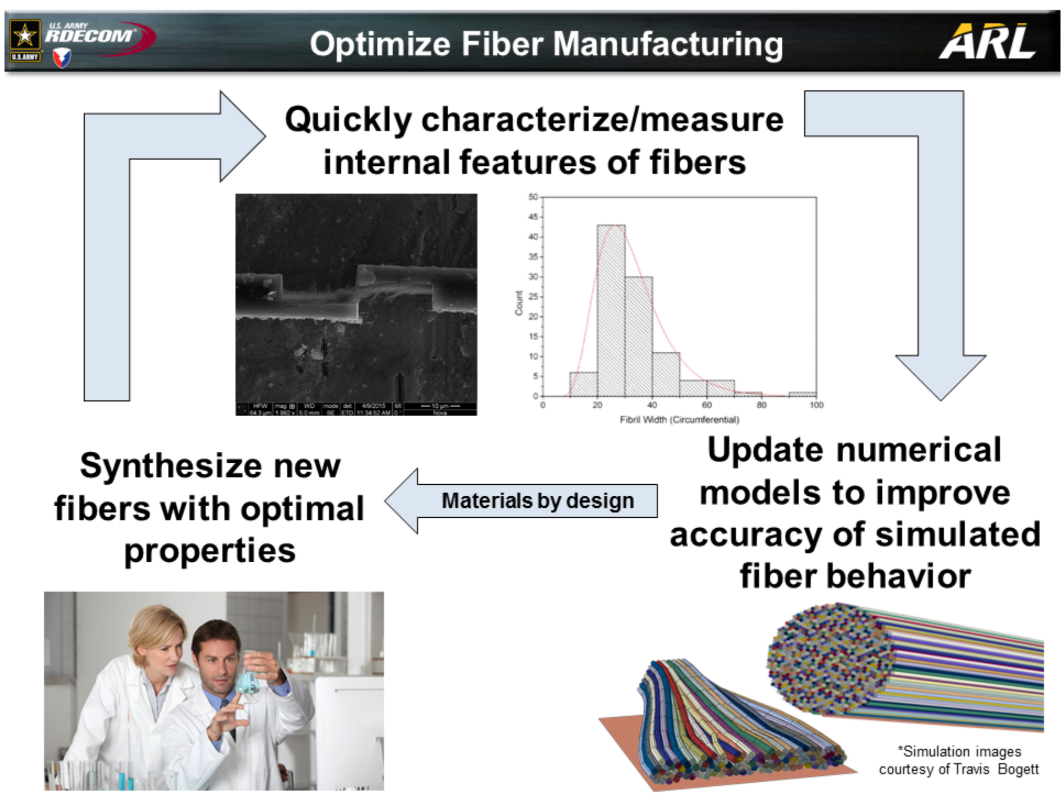
Armor performance is directly impacted by properties of individual Kevlar fibers.
20.0 µm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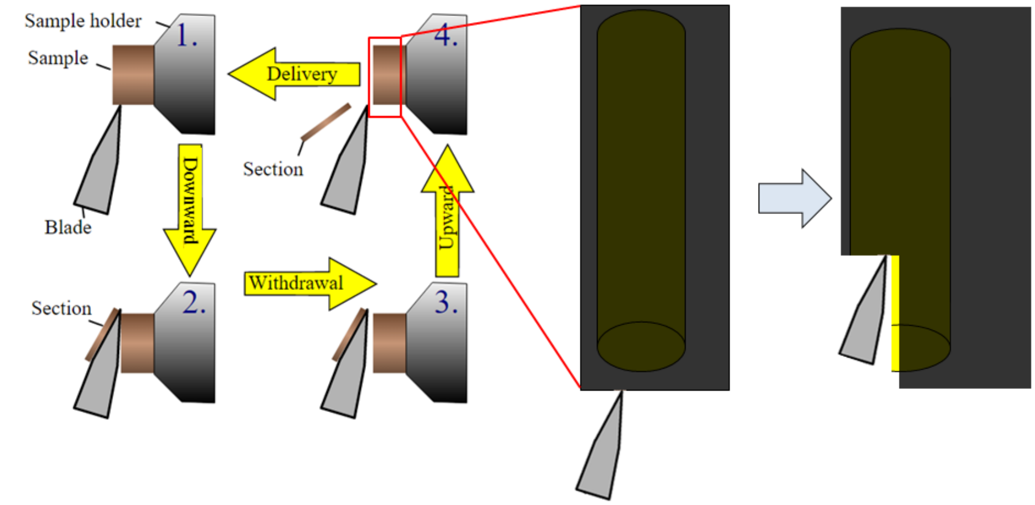
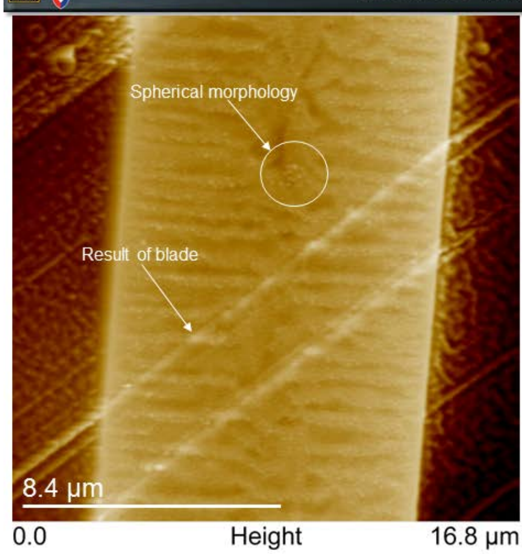
Optimize Fiber Manufacturing
ARL
Quickly characterize/measure internal features of fibers
Count
Fibril Width (Circumferential)
Update numerical models to improve accuracy of simulated fiber behavior
Materials by design
Synthesize new fibers with optimal properties
*Simulation images courtesy of Travis Bogett

Current Method: Microtoming



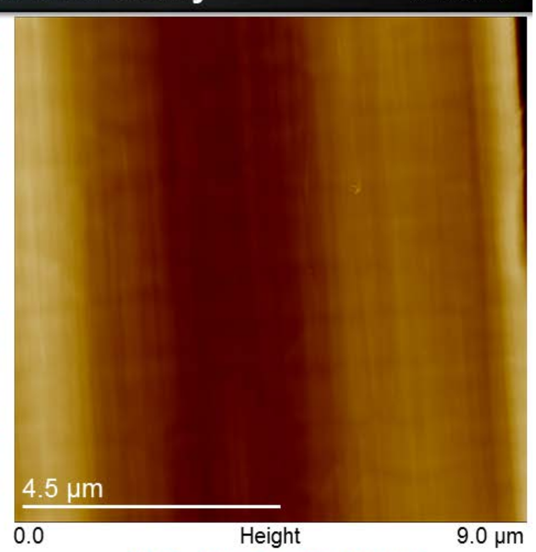
- **Very little work done to characterize internal features of high performance fibers**
- **Previous studies utilize microtomy to observe internal features of Kevlar and UHMWPE**
  - Dobb et al. Journal of Polymer Science (1977), McDaniel et al. Polymer (2015)

Issues with Microtomy



KM2 – Microtome

- **Lengthy process (≥24 hrs/sample)**
- **Sorting of features**
- **Odd spherical morphology develops over time**

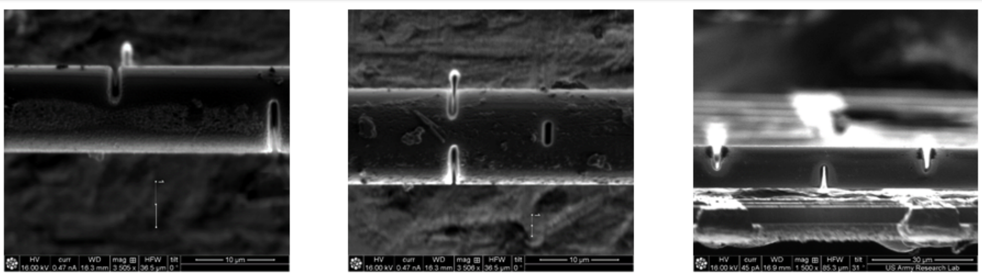


KM2 – Our New Technique: ***Induce Longitudinal Shear***

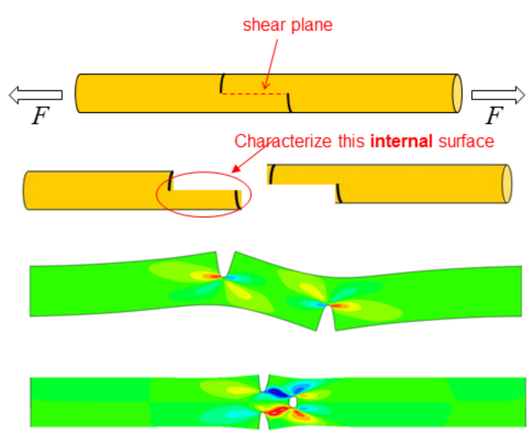
- **Time-efficient (<2 hrs/sample)**
- **No mechanical agitation of internal features**
- **No time-related effects**

Methodology

Longitudinal Shear Notching Experiment



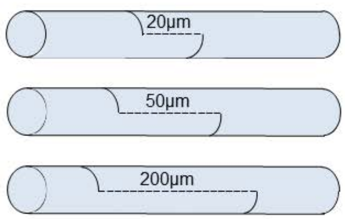
Objective:
Develop test methods for characterizing ballistic fibers after inducing longitudinal shear.



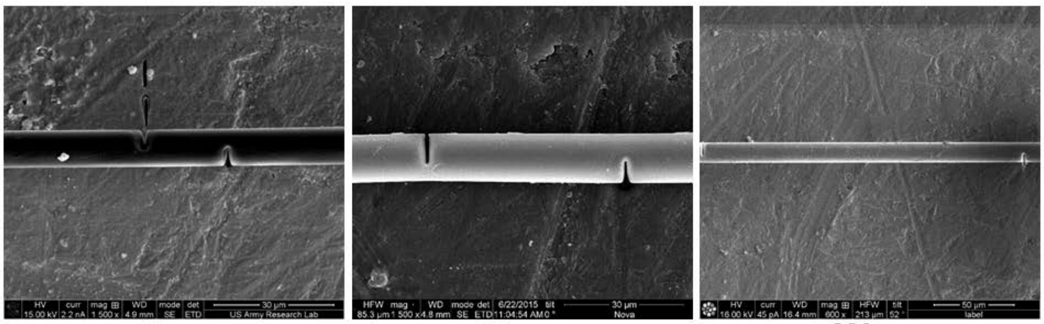
Approach:

- Use focused ion beam (FIB) milling to create notches in single fibers to produce a shear plane.
- Characterize internal surface morphology by atomic force microscopy (AFM).

Method: FIB Notches for Longitudinal Shear



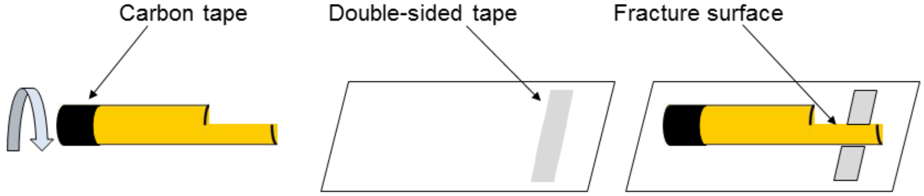
- Notches eliminate longitudinal strength of fibers making them extremely fragile
- Fibers fractured in tension
- After fibers are fractured they must be mounted in the correct alignment for imaging



20µm 50µm 200µm

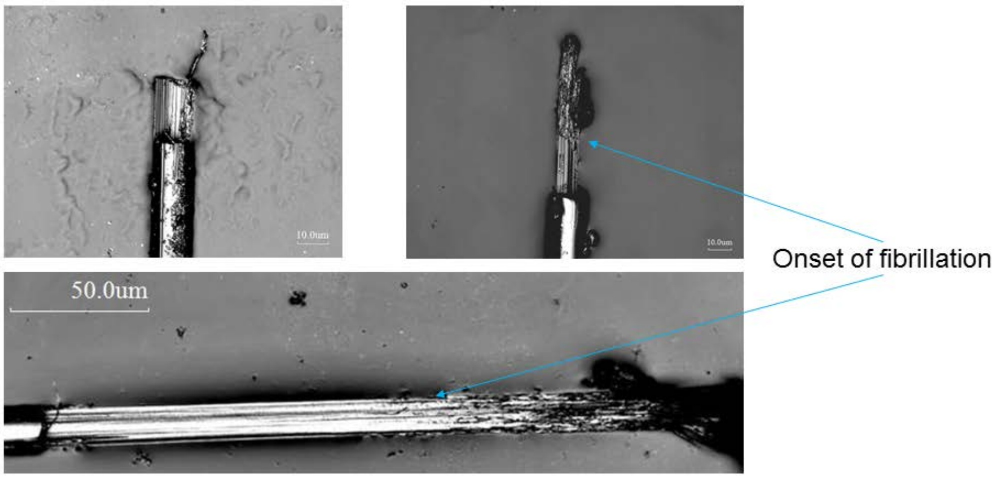
Method: Mounting Fibers for Imaging

- Fix back end of fiber to carbon tape allowing rotational freedom.
- Use optical microscope as visual aid and rotate fiber until fracture surface is facing up.
- Fix tip of fiber to double-sided adhesive tape to secure fiber for imaging.

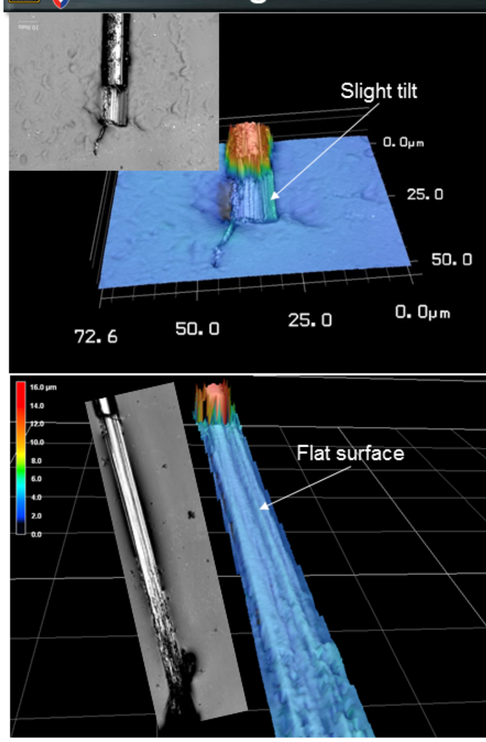


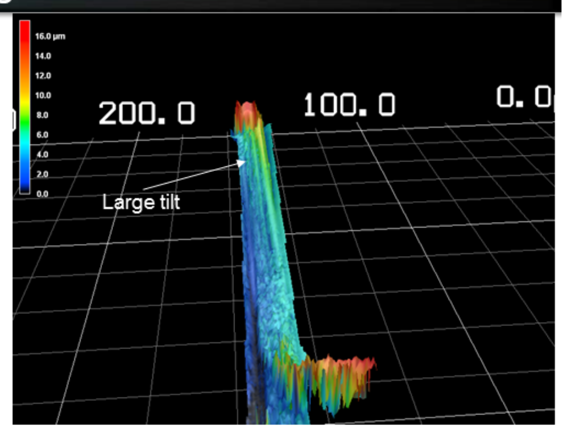
Method: Mounting Fibers for Imaging

- Initial imaging performed using Keyence 3D laser scanning confocal microscope.
- Height profiles are generated to confirm fracture surface alignment is maintained after mounting.



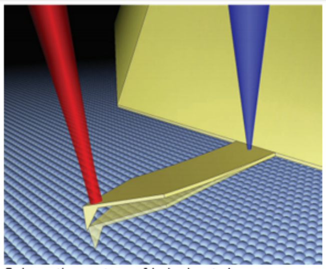
Height Profile Images of Fracture Surfaces





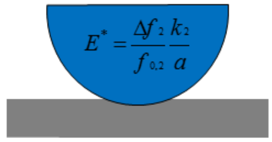
- Height profiles provide useful information prior to imaging with AFM
    - Confirm fracture surface alignment
    - Fracture surface step size
    - Location of features of interest

AFM Imaging Technique

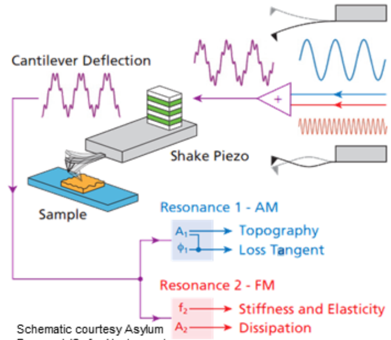


Schematic courtesy of Labuda et al.

Taylor expansion SHO
+ Hertz model
$k_{ts} = 2aE^*$

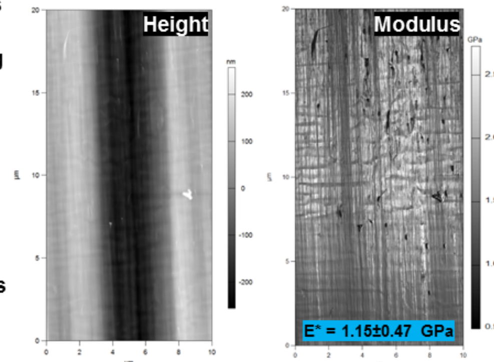


$$E^* = \frac{\Delta f_2}{f_{0,2}} \frac{k_2}{a}$$

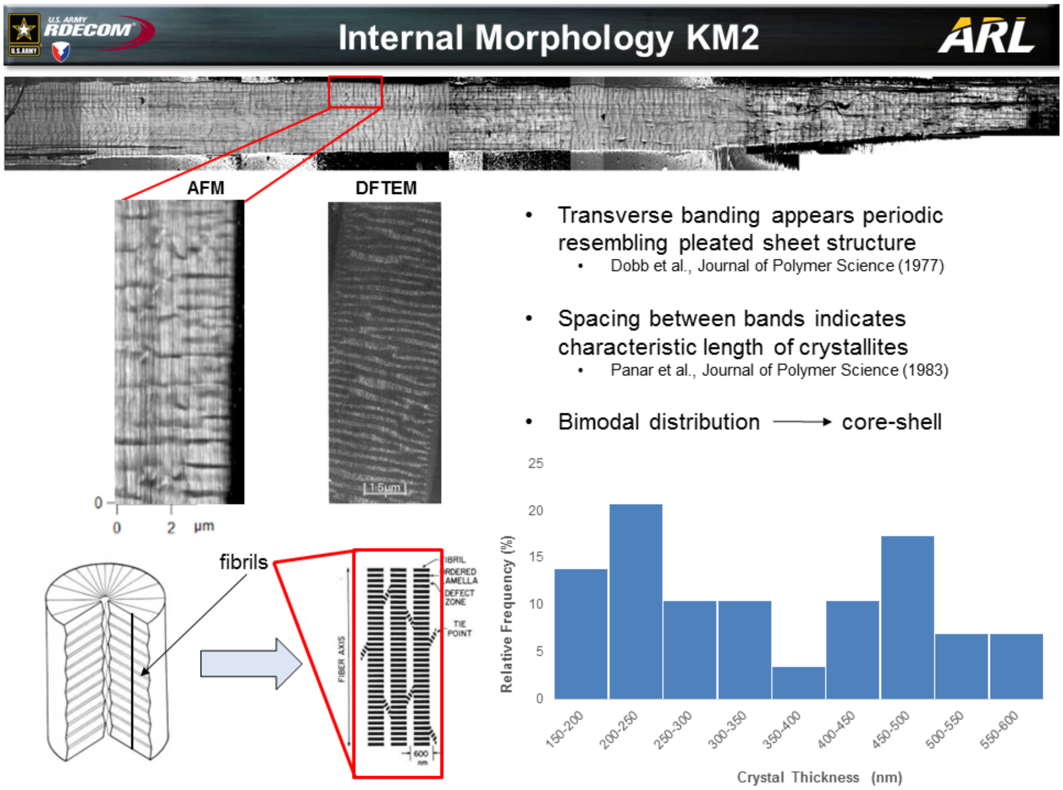


Schematic courtesy Asylum Research/Oxford Instruments

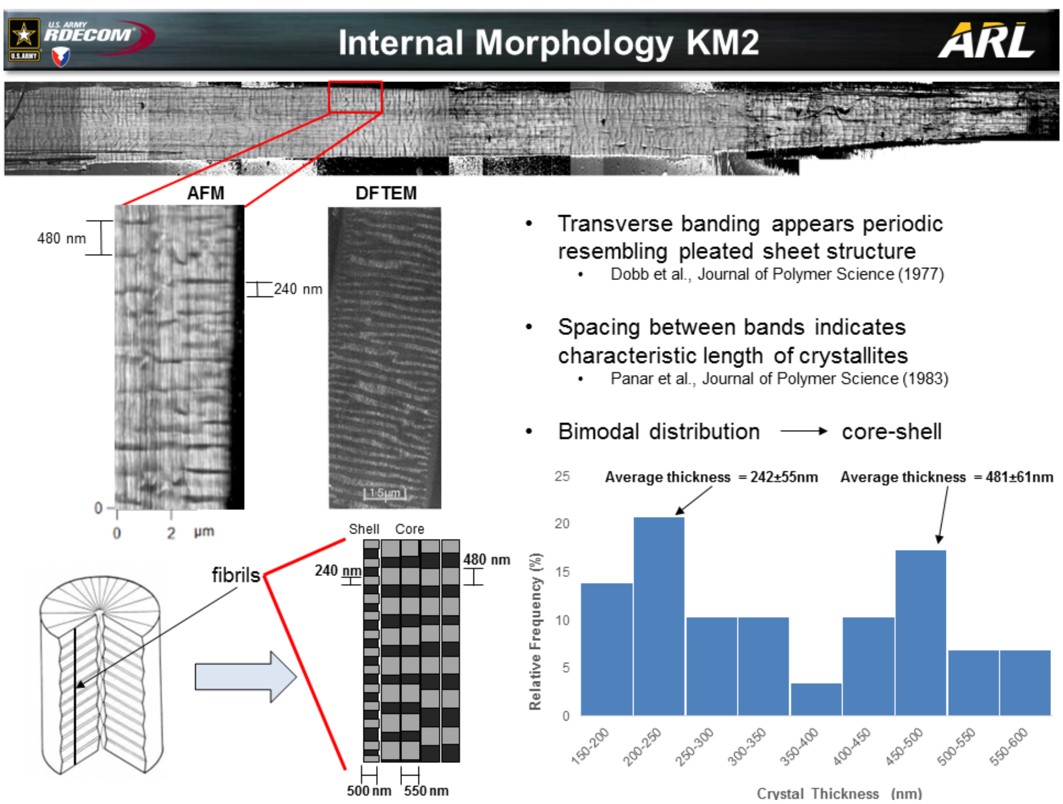
- Cypher's unique feature (blueDrive) directly drives cantilever with blue laser
  - Provides simple and extremely precise tuning of cantilever
- Operate in AMFM mode (Tapping mode)
- Generate modulus maps
  - Hertz model for contact mechanics
  - Changes in second resonant frequency correspond to differences in material stiffness



Results

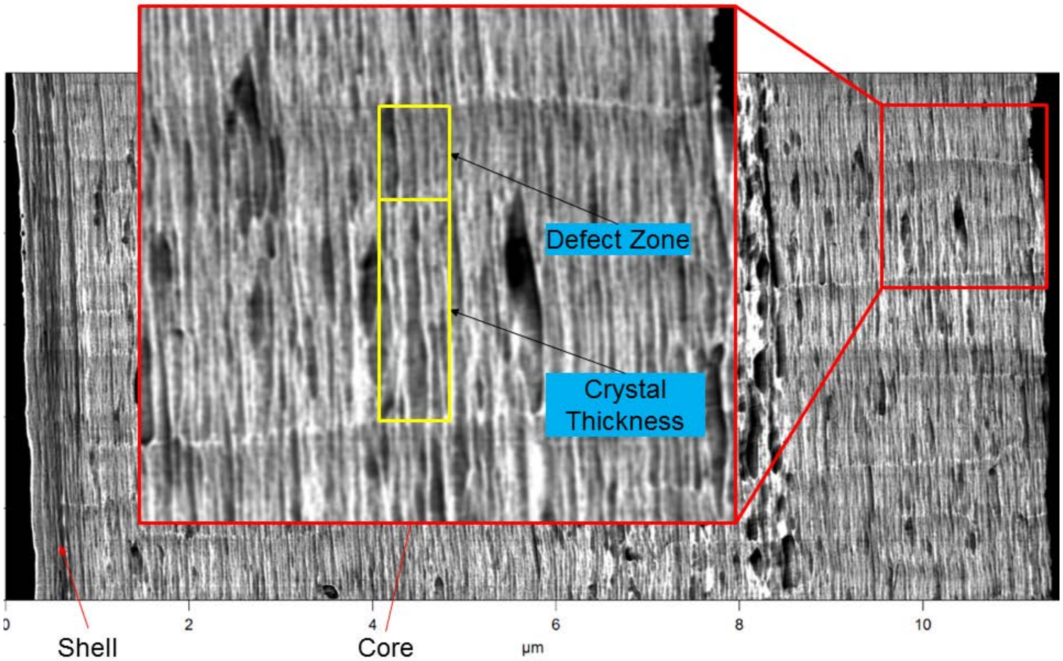


U.S. ARMY RDECOM
Internal Morphology KM2
ARL
AFM
DFTEM
0
0 2 µm
1.5µm
fibrils
FIBER AXIS
DEFECT ZONE
TIE POINT
600 nm
• Transverse banding appears periodic resembling pleated sheet structure
• Dobb et al., Journal of Polymer Science (1977)
• Spacing between bands indicates characteristic length of crystallites
• Panar et al., Journal of Polymer Science (1983)
• Bimodal distribution → core-shell
Relative Frequency (%)
0
5
10
15
20
25
150-200
200-250
250-300
300-350
350-400
400-450
450-500
500-550
550-600
Crystal Thickness (nm)



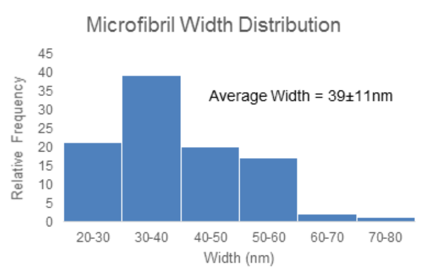
U.S. ARMY RDECOM
Internal Morphology KM2
ARL
AFM
DFTEM
480 nm
240 nm
0
0 2 µm
1.5µm
fibrils
Shell Core
240 nm
480 nm
500 nm 550 nm
• Transverse banding appears periodic resembling pleated sheet structure
• Dobb et al., Journal of Polymer Science (1977)
• Spacing between bands indicates characteristic length of crystallites
• Panar et al., Journal of Polymer Science (1983)
• Bimodal distribution → core-shell
Average thickness = 242±55nm
Average thickness = 481±61nm
Relative Frequency (%)
0
5
10
15
20
25
150-200
200-250
250-300
300-350
350-400
400-450
450-500
500-550
550-600
Crystal Thickness (nm)

High Resolution AFM Image

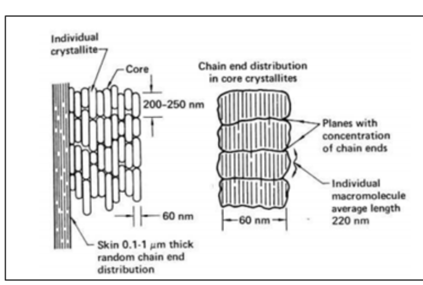


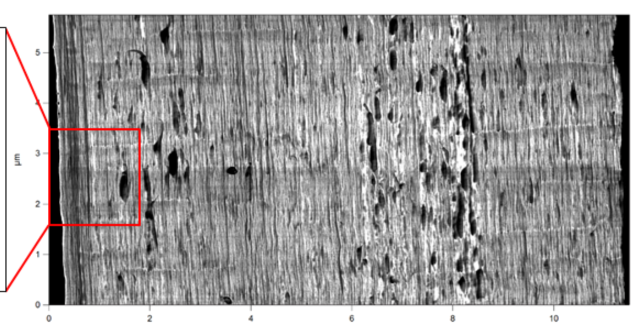
Internal Morphology KM2

- High resolution scan shows microfibrillar structure, which resembles chain-end model of poly(*p*-phenylene terephthalamide) (PPTA) fibers.
  - Morgan et al., Journal of Polymer Science (1983)



- Modulus of core = 1.15 GPa
- Modulus of shell = 0.84 GPa (~***<u>25% reduction</u>***)

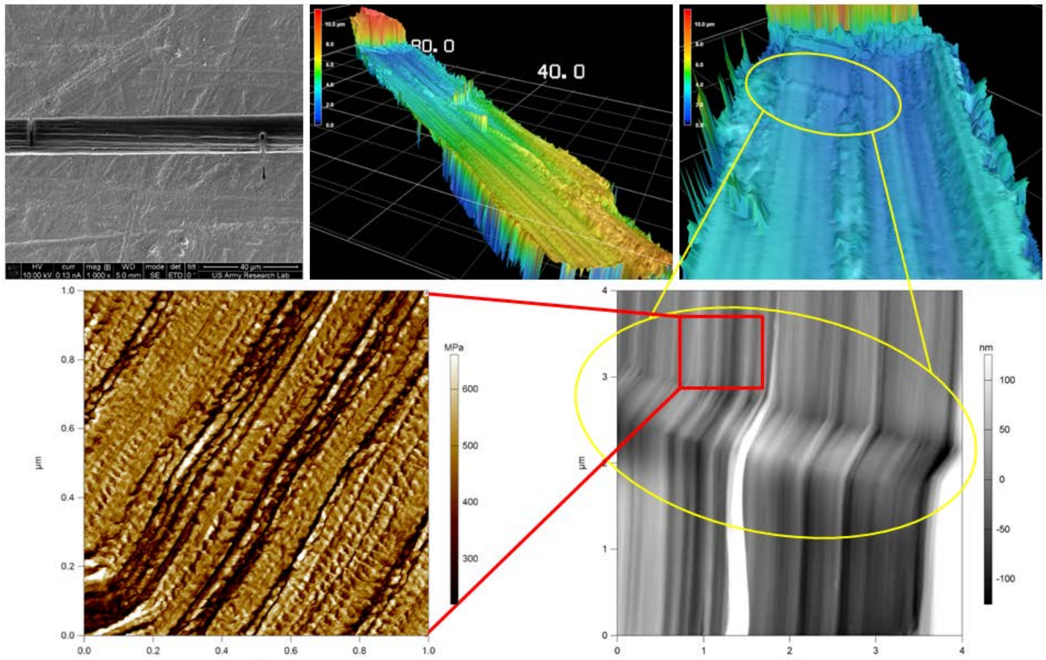




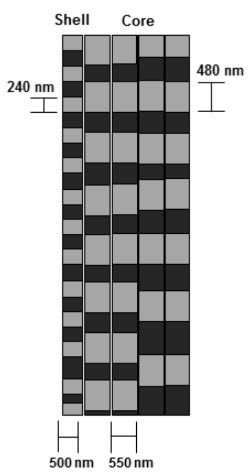
- Technique works for KM2 – what about other fiber systems?

Other Fiber Systems

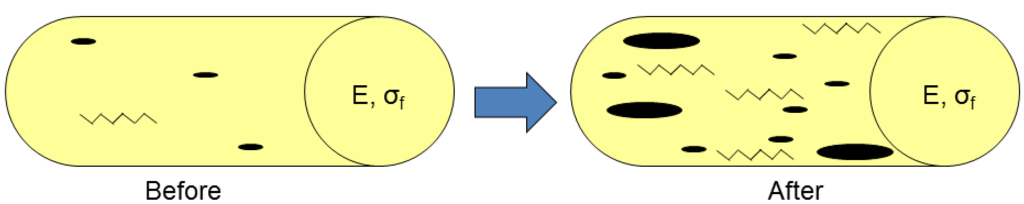
- Technique applied to observe internal morphology of UHMWPE fibers – Dyneema SK76



Connecting Morphology to Fiber Properties



- Mechanical properties known for single KM2 fibers
- <u>Next Step</u>: Correlate changes in internal morphology to changes in mechanical properties



Conclusions

- **Successfully induced longitudinal shear in single Kevlar KM2 and UHMWPE fibers using FIB notch technique.**
- **Internal features of KM2 resemble those observed in Kevlar 49 via DFTEM.**
- **Our new technique is more time-efficient and less disruptive than microtomy.**
- **Technique can quantitatively show how changes in internal morphologies effect overall mechanical properties.**

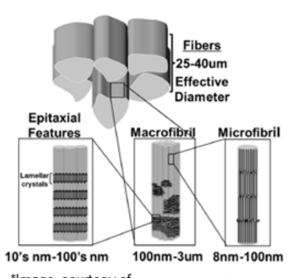
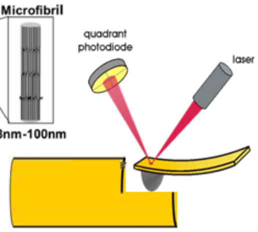
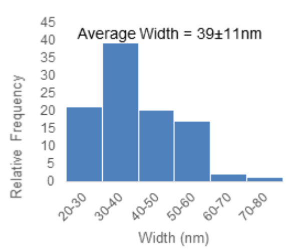
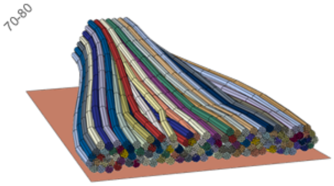


*Image courtesy of McDaniel et al.



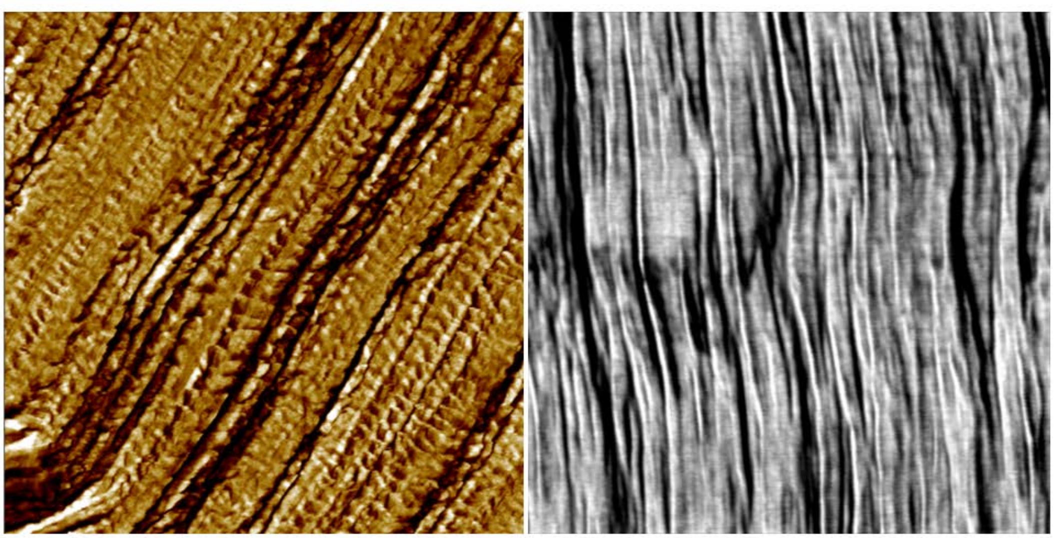




Acknowledgements

- Eric Wetzel
- Emil Sandoz-Rosado
- Ken Strawhecker
- Paul Moy
- Josh Taggart
- Jon Ligda
- Randy Mrozek
- ASEE
- CQL

Questions?



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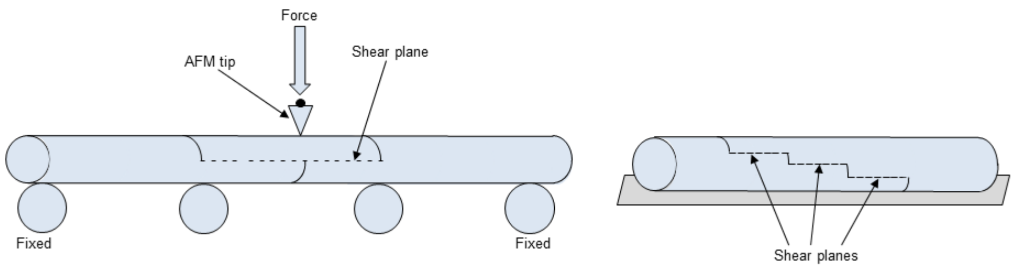
Shear Experiment Concepts

- TEM Grid 3-point bending
  - Short beam shear test uses 3 point bend test with span to thickness ratio of about 4:1 for inducing pure shear
  - 400 mesh TEM grid provides span:tk of about 5:1
- Stepwise shear surfaces
  - Provide through thickness observation of internal morphologies



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ATTN RDRL WML B ROSE PESCE-RODRIGUEZ

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